The Space Shuttle Challenger, high above the Kennedy Space Center and the Florida Atlantic coastline, heads towards its second earth-orbital mission. (Photographer: Astronaut John W. Young for the National Aeronautics and Space Administration)

AMERICA PLANS FOR SPACE

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A Reader Based on the National Defense University Space Symposium

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FOREWORD

Every day it becomes more apparent that future uses of outer space will ultimately affect the security of the free world. All nations will eventually use outer space in ways unforeseen today. Accordingly, free nations must plan now for the use of space by addressing the issue in public forums as well as in private councils among military planners and strategists.

Three decades of space exploration have produced quantum advances in communications, navigation, surveillance, and other defense-related systems. As we enter the fourth decade of the space era, the free world, led by the United States, must sustain its supremacy in space technology in hopes of assuring an unbroken future of peace.

This book, based on selected papers from the NDU Space Symposium 1984, chronicles recent achievements in space and outlines the challenges which face us as we push against mankind's new frontiers. The National Defense University is proud to contribute to America's planning for space by publishing this collection of wide-ranging, provocative essays.

Richard D. Lawrence

Richard D. Lawrence
Lieutenant General, US Army
President, National Defense
University

AMERICA PLANS FOR SPACE

Scientist-Astronaut Harrison H. Schmitt standing next to a huge, split lunar boulder during the third Apollo 17 extra-vehicular activity (EVA-3) at the Taurus-Littrow landing site. (This lunar scene is a composite of three views). Source: Manned Spacecraft Center, Houston, Texas.

PURSUING A BALANCED SPACE PROGRAM

Remarks at the NDU Space Symposium Dinner

VICE PRESIDENT GEORGE BUSH

If anyone needed convincing of the opportunities and potential offered by the further development and use of space—and you certainly don't—it seems to me that they would have to look no further than the benefits we have already derived from our space program. New technologies in rocket propulsion, electronics, heat-resistant materials, insulated and fire-resistant clothing, and many other areas have been developed through our space program. And, what is more important, many of these technologies have then been applied to commercial products, products that enrich our daily lives.

Our dependence on the use of space is growing in the civil sector, with electronic banking transactions, computer-to-computer data transfers, television programs being passed through satellites. We can use satellite data to help predict the weather, estimate crops, warn of some kinds of natural disasters, and improve geological exploration. In fact, in connection with the narcotics interdiction effort that the President has entrusted to me, we use satellite data to locate drug–producing fields.

The growing importance of space to our military security is similarly obvious. In this field, we rely on systems in space for such critical functions as communications, navigation, warning of a strategic nuclear attack, verification of treaties, and reconnaissance. And here, as in the civil sector, the importance of space's military applications will only grow with time.

Space offers us many opportunities: to develop more new technologies and new products, to advance manufacturing techniques, to create markets for services that did not exist before, and to create new jobs. Space offers us virtually limitless opportunities for economic growth. But those possibilities will be fully realized only if we take the steps to develop and steadfastly pursue a balanced space program. President Reagan supports a balanced and comprehensive space program. In his 4 July 1982 National Security Decision Directive (NSDD) on National Space Policy and then in more detail in his 15 August 1984 NSDD on National Space Strategy, the President spelled out the key elements and objectives of our space program.

The potential of the space shuttle for reliable regular space transportation should be exploited. The President has launched an initiative to commit us to building a permanently manned space station within a decade. Not only can this project be of enormous scientific benefit, but, on an even wider basis than the space shuttle, it can be a source of significant international cooperation. We will continue to maintain a vigorous program of scientific exploration missions. These missions, like Voyager and others in the past, will expand our understanding about our solar system and the universe beyond. We are also enthusiastic about opening the frontiers of space to vigorous, dynamic efforts of the US private sector, including reconsidering whether some traditionally government space missions might be more economically provided by private enterprises.

We must remember, however, that we are not alone in recognizing the vast potential of space. The Soviets, who orbited the first satellite and the first cosmonaut, have long had a successful space program. Regrettably, in contrast to our program, theirs can scarcely be called balanced. Our estimates indicate that about 85 percent of their space program is militarily oriented. In addition to vigorous development programs for a small space plane, for a Soviet version of our space shuttle, and for a new giant booster comparable to our Saturn V, the Soviets have the world's only operational space weapon—their antisatellite system—and the world's only space station, from which they perform both military and nonmilitary experiments. Against the background of this vigorous Soviet effort, especially with its important military component, it is only prudent that we explore the possibilities space offers for active defense against nuclear weapons. So I want to talk briefly about the Strategic Defense Initiative (SDI). Last March, the President set out boldly to rethink our present nuclear dilemma. He started from a very simple, moral premise: Wouldn't it be better to use our great technology to defend people rather than to threaten them?

We do not see an antinuclear defense as a substitute for either deterrence or arms control. On the contrary, we see an antinuclear defense as a way to make deterrence more secure while becoming less threatening. And we see the development of a defensive strategy as a positive adjunct to arms negotiations. Although we will make every effort to effect real, verifiable arms reductions, it may be that ultimately only a defensive shield can provide the climate of security and confidence on both sides that will make it possible, finally, to eliminate, or virtually eliminate, our nuclear stockpiles.

We should also remember that technology is our area of comparative advantage. Technology is our specialty, and we should use it to its utmost to keep deterrence as secure and as cost-effective as possible. When the critics understand that an antinuclear defense would complement effective negotiations toward dramatic arms reductions, they will join the President and the majority of the American people in supporting SDI research. We are compelled by logic and morality to find an alternative to the grim reality of the nuclear arms race.

We see space as a frontier of opportunity, for peace as well as commercial and scientific progress. Looking back on the short history of space flight, we remember some major milestones: Sputnik, the Gemini and Apollo missions, the first man to walk on the moon, the maiden voyage of the space shuttle some 10 years later.

The next, almost inevitable, step is a permanently manned orbiting station, our first real foothold beyond this planet. From there, we will have access to a whole new future of possibilities. Space is our New World, compelling, uncharted, and waiting to be discovered.

KEYNOTE ADDRESS: THE SPACE DEFENSE INITIATIVE

James A. Abrahamson

It is a great honor to talk to those of you here, from business and government, who have been part of decision-making in the first four decades of the space age, as well as to younger people who have been important contributors and who will make decisions in the future. Some of you, like me, fought and lived through World War II, the Korean War, and Vietnam. These were learning experiences, and surely one lesson they taught us is that there is no security in weakness.

In the same vein, we have all appreciated that the strength of a people cannot be measured solely in terms of armaments and wealth. As President Reagan noted in his inaugural address, there is no weapon in the arsenal of the world so formidable as the will and moral courage of free men and women. Obviously, will and moral courage have kept us a free nation—one in which creative men and women can do marvelous things in space, as well as in every other field of endeavor. That will and sense of resolve are also key to what we will do in the future.

However, we cannot ignore the harsh reality that over the past three decades the Soviet Union has achieved greater advances in military power than any other nation in the world. This does not mean that the Soviets are ahead, but they have advanced in a consistent and determined way. The statistics, indicating their advantages in surface-to-air missiles, armored vehicles, artillery, tactical aircraft, naval and service combat ships, submarines, intercontinental ballistic missiles, and submarine-launched ballistic missiles indicate advancement in every field of military deployment.

It is also clear that the Soviets have invested great sums in ballistic missile defenses and, of course, they have the world's only operational antiballistic missile system. Their gross national product (GNP) is just a little over half of ours, yet the dollar cost equivalent of their military effort (and there are many different measures of that) appears to be consistently about 40 to 50 percent larger than ours. Their defense effort unquestionably enjoys absolute primacy in both their economic and their industrial plans. Although the challenge from the East remains great, I do not want to begin this conference only in the framework of "we versus they." We must understand that we are not weak today. The pace of Soviet military effort, however, could lead to both relative weakness and very great danger for us.

The President knows this. On 23 March 1983, he reminded us of two important promises he made to the American people as he began his first term. First, to restore our neglected defenses in order to strengthen and preserve the peace, and second, to pursue a reliable agreement to reduce weapons. As part of the program to restore our neglected defenses, the President gave us a goal and an entirely different strategy, one that had been abandoned, primarily for technical reasons, in the past but has now come to be accepted. In the face of some different and dangerous long-term trends, the strategy is now worth reconsideration. His challenge has led to a comprehensive and intensive effort to define a long-term research and development program from which we may begin to achieve a new national goal: elimination of the threat posed by strategic nuclear missiles. He describes it as a vision of the future that offers hope.

We all know this plan as the Strategic Defense Initiative, often called "Star Wars." It obviously conjures up visions of advanced technology, but I think such visions are misleading. Many other misleading labels, examples of what I sometimes call "bumpersticker logic," have been applied to the program. Critics say that our objective is to militarize space or to take war to the heavens. That is clearly *not* the objective. I want to put the administration's strategy of hope in a larger perspective—into the context of America's future in space, the theme of this symposium.

Since 1945 the world has made remarkable technical progress in all areas of space activity ranging from the dramatic scientific and exploration programs that marked the beginning of the space age to the commercial program that is now beginning to pay off for this nation. In each area, technical progress has been matched by new perspectives, giant intellectual leaps in understanding, and new confidence on the part of people everywhere in what human beings can accomplish. We have even incorporated that confidence into our everyday language: "If we can go to the moon, why can't we do this or that?" What we are really saying is that we believe we can do anything.

Many of you in this room are part of the spirit and force that have made these miracles possible. You share both in the credit for where we are today and in the responsibility for this age in which people are willing to meet any challenge, no matter how difficult. Clearly, a continuing part of that responsibility is foreseeing new opportunities, selecting the right goals, articulating the possibilities and choices, and, finally, making these dreams become reality. That is why some of the most distinguished dreamers and doers in America will be speaking here at this conference. They will talk to you, participate in your discussions, exchange ideas, and examine initiatives that promise even more progress. Together we will all consider specific concepts and where they may lead.

My purpose now is to remind you that this confidence does not grow out of several individual, isolated initiatives and proposals. The most portentous fact in this conference, and in this age, is that the sum of all of these initiatives and the relationship among them means that we are moving into an entirely new space age. Clearly we are exploiting the space shuttle. All our security programs in space are flourishing. We have embarked on a new space station effort, a permanent manned presence in space. Our scientific and commercial enterprises are leaping ahead.

And, of course, we have the Strategic Defense Initiative (SDI). You have heard and read about the objectives, the architecture, and the technology of this program, so I will not spend a great deal of time on those, but I will remind you why we are doing what we are doing in this program.

Our first objective is to focus on a completely different concept of deterrence: a defensive kind of deterrence. We have never abandoned the idea of deterrence, but we are looking for a more stable concept of deterrence. Should today's offensive deterrent somehow tragically fail, even partially, we would be on the brink of what could be a disaster for all of mankind. With the Strategic Defense Initiative, should deterrence fail, there will remain a real capability that could still avert disaster for mankind. When people talk and think about what those aspects of the initiative mean, they often forget that, although President Reagan challenged scientists to find a way to increase the security for all of us, he also challenged the arms control community when he said, "If we can reduce the value of nuclear ballistic missiles, we should be able to also find ways to remove the weapons themselves."

So SDI is not just a technical initiative, it is also a political and strategic initiative. All aspects of the program are being aggressively researched and we are trying to put them together in a way that moves us toward this objective of improved security for all mankind.

Let me return to the SDI architecture briefly, which is very different from the architecture we abandoned in 1972 and 1973. Then we had a thin layer of defense based on a technology that was stretched and clearly unable to meet the future threat. SDI is quite different. Its architecture starts with an attempt to get maximum military advantage by destroying missiles as they rise from silos, or from the sea, or from some hidden location. Because some of these missile targets will be missed, we will try to maintain our military advantage by destroying buses in the boost phase, before all the warheads have spun off and the hundreds of decoys are deployed. Again, some will get through, and we will be faced with thousands of objects in space. We have to develop systems that can see and discriminate among those objects in such a way that we can then try to destroy, in midcourse, the large remaining portion of those warheads. Finally, only a few of them would be left for the terminal area and final defense. The entire architecture is aimed at providing defense for the United States and its allies. SDI is not a way to separate the United States behind an astrodome type of defense, but a way to draw the whole Western world together more effectively. Most important, we hope that this initiative will drive the Soviet Union to seek to guarantee its security in less offensive ways. We must ensure that our research is aimed not just at the technical feasibility of creating a defense of this kind, but also at providing a motivation for the Soviets to—

- Stop investing in more obsolete offensive weapons;
- Invest their time and effort instead in defenses, so that they feel more secure;
- Adopt the idea of a defensive deterrent; and
- Be willing to begin to negotiate away these destabilizing and very dangerous weapons.

How can new developments in technology motivate the Soviets in these ways? You have all heard about the important effort we are exerting in directed-energy weapons. We have a chemical laser, one of the largest in the free world and perhaps the largest in the world, operating today at the White Sands missile range; we have an operating directed-energy system, a neutral particle beam system, at the Los Alamos National Laboratory; we will soon be ready to operate the largest free-electron laser system at the Livermore Laboratory; we also have many industrial laboratories operating. We do not have to invent major, new scientific advances—inventions which, if necessary, would substantially delay our ability to create these advanced weapons. However, I would emphasize that we do have to find ways of making these weapons cost-effective. The Soviet Union will not move in the right direction until its leaders understand that they cannot overcome our investments in defense with a lesser investment in offense. Until that time, they will be inclined to build more offensive systems to counter us. They must understand that we have a powerful technology. That is why we're looking at these directed-energy systems. But they are not the only technological advances.

Even nearer term than the directed-energy systems are some of the more conventional and effective systems using technology that owes its maturity to the security industries in many other programs. We have chemical weapons that could be used in unique and effective ways. We now have operating railguns, guns that use electromagnetic field forces instead of powder charges to accelerate weapons with firing velocities in the range of 8 to 10 km per second. We have to be able to extrapolate them up to velocities of 30 or 40 km per second.

The technology behind these weapons is also an important part of our trust. We will be developing cryogenic coolers that will allow us to use infrared sensors for the discrimination test that I talked about, and to do it effectively over a long time in space. We are investigating the possibilities of using large vehicles to bring down the cost of space transportation perhaps by factors of 10 from the current cost using the space shuttle. We are investigating space power systems that can provide the huge megawatt levels that will be required to operate directed-energy and other systems in space. So this technology cuts across a great range of effort.

But the important thing is not simply what these technologies can do for SDI today and in the future. We must link them to a space station that will help us achieve a permanent, manned presence in space. Coupling the sophisticated computer operations and communications already being used in national security programs to the tremendous advances that are being made and the large amounts of money that are being spent on space technologies through commercial enterprises clearly portends a marvelous future.

Progress will not be only in technical areas, however; there will be further advances in ideas and perspectives in human progress. Vice President Bush put it well when he said that we did not go to the moon in order to build Teflon frying pans.

Nonetheless, the technological thrust in all these areas, combined with our efforts to exploit the advances and to understand what they can do, will mean that the next century is going to be dramatically different for everybody.

The new space renaissance will bring about changes so significant that none of us can imagine them. We in the United States and our friends are leading half of that effort, but only half. A hundred and fifty years ago, Alexis de Tocqueville had a remarkable insight into the world of the 1980s. He wrote about the peoples of two great nations in the world, the Russians and the Americans. They start from different points and take different courses, yet each seems marked by heaven to sway the destinies of half of the globe. The Americans struggle against obstacles imposed by nature, while the Russians struggle against men. The Americans combat the wilderness and the savage life; the Russians, civilization itself.

There can be no question that de Tocqueville's observations will continue to be valid for a long time to come, and that the Soviet challenge I have talked about will continue. But be assured that the story you will hear today about our vision of the future in science, security programs, and commercial enterprises in space will change the force and the direction of civilization. It is up to us to ensure that the direction taken is one that we in the West believe in for ourselves and for our children. We must ensure that we bring the maximum return of this new space age to all the people of the world for the enduring benefit of mankind. So as you examine, listen, and probe each of the discussions during this conference, remember that the future is in our hands today. We can achieve anything that we want. So let's make the right choices and demonstrate good results.

WARFARE IN SPACE

Hans Mark

Ever since the first orbital flight by the Soviet Union's Sputnik I in 1957, people have been speculating about what operations in space mean to the conduct of war. As it turns out, there are some good historical precedents that can be examined to help us understand what we can expect. The primary functions carried out by national security-related satellites today are surveillance and communications. The first flying "machines," lighter-than-air balloons, were used for essentially the same purpose. The hot-air balloon was invented by the Montgolfier Brothers in the last years of the 18th century, and before long hot air balloons were applied to military operations. Like satellites today balloons gave the observer a much broader, synoptic view of the field of conflict than anything else could provide from a vantage point on the ground.

At the Battle of Fleurus at Maubeurge in 1794, the French used balloons for surveillance of the battlefield, and their employment proved to be decisive in the battle. In 1849, balloons were employed by Austrians, to drop bombs on the city of Venice. During the American Civil War (1860–1865), the Union Army actually organized a balloon unit for reconnaissance and artillery spotting. In 1870, balloons were used for similar purposes during the Franco-Prussian War. As the range and accuracy of artillery and small-arms fire improved, balloons proved to be impractical as airborne observation platforms because they were too vulnerable.

When flight using heavier-than-air machines was proved possible by the epoch-making experiments of Wilbur and Orville Wright in December 1903, the military applications of the new vehicle quickly became obvious. In February 1908, by which time the Wrights had clearly demonstrated that sustained flight was possible for extended periods of time, they signed a contract with the US Army Signal Corps to produce the first military aircraft. It is significant that the Signal Corps was the branch of the service first interested in airplanes, because it was responsible for providing the information the ground commanders needed to fight the battle. Soon aircraft much like the ones built by the Wrights were used in actual combat situations. The first recorded use of an aircraft during a military operation was in a skirmish between Italian and Turkish troops in North Africa in 1911. The effect the Italians' use of aircraft had on the outcome of this incident is not recorded.

In 1913, the youthful Igor Sikorsky, who was later to play the leading role in the development of the helicopter, built what was then the world's largest airplane for czarist Russia. It was called the "Ilya Mourometz" and it set a number of world records, including one for a nonstop long-distance flight from Kiev to Petrograd (now Leningrad) and return—a distance of 1,600 miles.

In the early months of World War I, both sides used aircraft for reconnaissance purposes in much the way that balloons had been used in earlier conflicts. Each side quickly developed means for attacking the aircraft of the other, and air warfare soon evolved to the point at which the air above the battlefield became a separate field of conflict. Planes were developed to "pursue" and shoot down the enemy's reconnaissance aircraft. Rapid strides were made in the technology of large aircraft and, by the end of World War I, both sides possessed large, long-range bombers capable of reaching each other's population centers. German "Gotha" bombers raided London and the British Handley-Page machines raided cities on the continent.

By the end of World War I, all the significant elements of air power were in place: fighters for air-to-air combat, bombers for the attack of targets on the ground, observation aircraft for reconnaissance, and transport aircraft for movement. Several nations, Great Britain, France, and Germany, among others, believed that air warfare was so important that they established separate military services to deal with air combat. Other countries, such as the United States and Japan, chose to keep their air services attached to the traditional services, the Army and the Navy, and did not set up separate air services until after the end of World War II. During World War II, all these elements were refined, while aircraft carriers added the new element of maritime air capability. However, no fundamental changes were made in the doctrines and principles of air warfare that had been established during World War I.

EARLY SPACE OPERATIONS

At the conclusion of World War II, the Cold War between the United States and the Soviet Union began. Again, the function of reconnaissance was crucial, and both sides developed sophisticated technical means for gaining information about what the other was doing. In the early 1950s, the Lockheed U-2 reconnaissance aircraft was created in an extraordinary technical tour de force by Kelly Johnson and his collaborators. For a number of years, these remarkable airplanes flew over "denied" territory with impunity because they could fly at such extremely high altitudes that the then-available antiaircraft fire could not reach them. The U–2s gathered much useful information on which political decisionmakers came to depend. During the same period, the technology to put man-made satellites in Earth orbit was also being vigorously pursued. As a result, when in 1960, the U–2 era was brought to a close by the Soviets' downing of the airplane flown by Francis Gary Powers, earth-orbiting satellites that could perform similar functions were almost ready to be deployed. The first of these was launched in the early 1960s, and these satellites have played an increasingly important role since that time.

Satellite reconnaissance is of fundamental importance because it reduces the uncertainties that our political leaders face in making important decisions related to the national security. It is really for this reason that the Soviet Union and the United States agreed in the 1972 Arms Control Agreement (SALT I) not to attack each other's "national technical means of verification," the euphemism then employed for photoreconnaissance satellites. (President Carter did not publicly announce that the United States possessed photoreconnaissance satellites for the purpose of verifying arms control agreements until 1978.)

Despite this agreement, the Soviets were already well along in the development of an antisatellite system designed to shoot down the surveillance satellites of the United States. The Soviets made this heavy investment because they recognized that these satellites are much more important to the United States than the equivalent systems are to the Soviets. It was a graphic illustration of the problems that an open and free society such as ours has in dealing with a closed, tight-fisted tyranny. The Soviets have many ways of gaining information about the United States other than using earth observation satellites, but the United States must rely much more on its satellites for information about the Soviet Union. This is why the Russians have already developed and fielded an antisatellite system that is now operational. The American satellites perform a very valuable function and the Soviets know this. They therefore wish to have the capability to deny us these functions. Thus, the pattern that was established in the development of aerial warfare has continued in the case of space warfare as well.

Air warfare developed from surveillance and communications missions to strategic bombing in less than half a century. To a remarkable extent, the first military-related missions in space have been a replay of what happened in the early days of aviation. All the world's major space-faring nations, the United States, the Soviet Union, France, China, and Britain, have deployed satellite systems that have been used either for surveillance or for communications of military value. Because these functions are valuable, both the Soviet Union and the United States have either fielded or are developing means to shoot down these satellites, just as, in an earlier period, the means to shoot down early reconnaissance balloons and aircraft were rapidly found. Thus, because the potential to deliberately destroy earth-orbiting satellites exists, the era of warfare in space has opened.

It is the purpose of this paper to explore the consequences of this situation, to make some reasonable technical projections, and to suggest some doctrines that might be properly applied to the conduct of military operations in space. For the present, the discussion will be limited to earth-orbiting vehicles, although it is clear that this topic is closely related to what might be done to build a defense against nuclear-armed ballistic missiles.

ANTISATELLITE WEAPON SYSTEMS

Although the Soviet antisatellite system, which was tested successfully for the first time in 1972, is technically a relatively primitive device, it has proved effective in a number of tests. In this antisatellite system, the Soviets' weapon-carrying satellite must maneuver into the same orbit as the target satellite, execute a close approach, and then detonate a conventional shrapnel type of explosive warhead to destroy the target. Probably the best way to defeat such a "co-orbiting" satellite system is to detect the antisatellite vehicle as it approaches and then maneuver the target out of harm's way. This can be done because co-orbiting systems of this type must have very slow approach velocities. The target satellite simply requires a detector to pick up the homing radar on the antisatellite vehicle and enough propulsive capability to get out of range of the shrapnel explosive device. Outfitting the target satellite to avoid being hit requires that it carry some extra weight not directly connected to the satellite's primary capability to execute whatever mission it has. Because weight is always at a premium on spacecraft, this price may be very high indeed. Hence, the usual engineering tradeoff between offensive and defensive capability—such as between guns, armor, and speed on a warship—becomes much more tightly constrained. As a result, little has really been done to make satellites survivable.

In the summer of 1957, even before Sputnik I was launched, Nicholas C. Christofilos, working at the Lawrence Livermore National Laboratory, suggested that nuclear explosives might be a good means for bringing down hostile satellites. He was particularly interested in the damage that might be done by the energetic charged particles (electrons and protons as well as heavier ions) that are injected into the magnetosphere by the nuclear explosion. These charged particles execute relatively stable orbits around the Earth by the Earth's magnetic field, and enough of them can be put into the magnetosphere by a relatively small number of nuclear devices to do significant damage to many types of satellites. Because these energetic particles quickly spread around the entire globe, it does not matter very much just where the original nuclear explosion occurred. In 1962, a megaton-range-yield nuclear explosion above the atmosphere (Starfish) was able to put a number of satellites temporarily out of commission. This happened more or less inadvertently in the case of Starfish because it was not known at the time how to estimate the number of particles that would actually be trapped. If several weapons of this size were properly placed by design at the right location and detonated, much more damage could be done.

If a nuclear explosive is detonated close enough to a satellite, the x-rays emanating from the blast will kill the satellite. Nothing can be done to protect satellites at ranges up to hundreds of kilometers. Thus, if a belligerent power is willing to invest a few nuclear weapons at the beginning of a conflict, none of the current surveillance or communications satellites that the other side has in orbit will survive. Probably the most important point that needs to be understood about space warfare is that the use of a small number—a dozen to 20—megaton-yield nuclear explosives could destroy or neutralize almost all the militarily important satellites. It would be extremely difficult to protect satellites against such an attack.

There is probably some political "threshold" against using nuclear weapons that might deter their use for this purpose. Also, nuclear weapons and their delivery systems are expensive, so a potential aggressor would most likely want to use them against targets of higher value than the satellites. Finally, large nuclear detonations might also kill the aggressor's own satellite surveillance system and this possibility could deter him from using nuclear explosives. It is most important to recognize, however, that these deterrent factors may not be strong enough. The military planner, therefore, must live with the fact that it is impossible to protect orbiting satellites against a determined and intelligently planned attack using nuclear weapons.

There is every reason to believe that in the coming years new methods of destroying orbiting satellites will be developed that do not have the drawbacks of the Soviets' co-orbiting satellite system or of the methods that rely on the use of nuclear weapons. The United States is now working on an antisatellite system based on the technology of miniature homing vehicles that have onboard sensors capable of following the moving target satellite and "homing" in on it to destroy it, also with a shrapnel type of explosive device. These vehicles would be launched using small but powerful solid fuel rockets carried on fighter aircraft such as the F–15. The miniature homing vehicle is not a co-orbiting system but, rather, it approaches the target on a direct trajectory and relies on the homing sensors and a very accurate guidance system to get close enough to the target so that "kinetic energy" kill mechanisms are effective. The relative closing speed of the miniature homing vehicle on the target satellite is very large compared with the speed of a co-orbiting system. Therefore, if the weapon is to work properly, the guidance systems (that is, the onboard trajectory computer and the thrust vector control system) must be exceptionally good.

The closing speed problem, of course, presents the largest technical difficulty in the development and design of space-based weapons. Unlike conventional aircraft, which need to move at speeds of only a few hundred miles an hour to sustain forward flight, a spacecraft must have velocity of 17,000 miles per hour in order to sustain itself in Earth orbit. Therefore, unless an attacking spacecraft is in nearly the same orbit as the target (that is, it co-orbits with the target) the attacker will encounter high relative velocities. These high relative velocities imply a formidable fire control problem. It is this consideration that has led many people to speculate that lasers of some type may be the best weapons for space warfare in which the primary objective is to destroy the enemy's satellites. Lasers have the great advantage that the energy used to destroy the target travels with the speed of light—which is always much faster than the speed of a target in any practical situation. Therefore, the normal "lead" calculation in the fire control problem is greatly simplified, compared with the case in which the destructive energy is carried by a projectile that travels with a speed comparable to the speed of the target.

LASERS

Although the principle on which lasers are based, the stimulated emission of electromagnetic radiation, was discovered in 1917 by Albert Einstein, the first successful laser was not produced until 1962 by T.H. Maiman and his collaborators. In addition to understanding the principle, scientists had to develop the means for applying in practice what Einstein had discovered in theory. The essential problem of the laser was then, and is still, that it is inefficient. This means that not much of the energy used to produce the laser beam actually winds up in the beam in such a way that it is capable of doing damage of military interest. Operational gas dynamic lasers today have efficiencies of the order of 5 percent—that is, 5 percent of the energy required to produce the laser beam actually goes into the beam. Although beams having fairly high intensities—of the order of several hundred kilowatts to perhaps one megawatt—have been produced, the lasers capable of doing this require large and complex installations. Some promising concepts, especially in the area of chemical lasers and free electron devices, appear to have much higher efficiencies than the currently available gas dynamic lasers do. Thus, there is good reason to believe that research and development in this field will yield much progress.

Despite these difficulties, significant progress has been made since 1962 in the creation of lasers with the capacity to do damage at ranges that might be of military interest. We have developed lasers that have destroyed air-to-air missiles in flight in an experimental setting. A large laser has been placed on a large transport type of airplane, the Airborne Laser Laboratory, which has demonstrated the ability of lasers to destroy missiles of various types from airplanes. In conducting experiments with the Airborne Laser Laboratory, we have learned much about the fire control problem and the technology of packaging lasers to minimize weight and size. Both of these areas will be important when the time eventually comes to place high-intensity lasers in space for military purposes.

Even though it is difficult to produce lasers capable of doing damage of military interest to "normal" targets, antisatellite lasers may become practical because their intended targets—the satellites—are flimsy and vulnerable structures. For example, a ground-based laser that can deliver a beam intensity of the order of 10 megawatts with reasonably good optics can do enough damage to certain satellites in near Earth orbit to put them out of commission. Most solar cells in use today for satellite power systems would be vulnerable to damage from a ground-based laser of this type. Practical lasers in the 10-megawatt power level have yet to be built, but there do not seem to be any compelling technical reasons why they cannot eventually be developed. If a hostile power actually fields such a laser, we will have to take measures to protect satellites against attacks from the device.

For the next decade or so, the threat from a ground-based laser of the type described is the most serious one posed to current satellites by laser technology. The problem of "hardening" satellites against the threat of ground-based lasers is not insuperable because of the relatively low energy density delivered by ground-based lasers. Nevertheless, even this hardening effort would be costly.

In the long run, however, the threats that might be caused by the existence of space-based lasers should also be considered. Placing high-intensity lasers in orbiting space vehicles and developing the command and control system to use them present formidable technical challenges. A number of approaches have been suggested ranging from relatively "conventional" lasers adapted to work in space to x-ray lasers driven by nuclear explosions. Over a time scale of two decades, both these approaches are promising, and rigorous development and test programs should be pursued to learn what can be done.

SATELLITE SURVIVABILITY

What can be done to protect orbiting satellites and launch vehicles such as the shuttle against the near-term threats that have been described? Considering the value of reconnaissance and surveillance satellites, succeeding administrations in this country have expressed continuing concern over the problem of satellite vulnerability. Actually doing something concrete, however, turns out to be distasteful and expensive because of the stringent weight constraints for satellite systems. Significant defensive measures almost always compromise the satellite's capability to perform its primary mission beyond the point that has been considered profitable. It is probable, nevertheless, that satellites can be built that can somehow deal with the near-term threats. The possibility of maneuvering out of the way of coorbiting antisatellite systems has already been mentioned, and this technique sometimes has the advantage that additional maneuvering capability enhances the primary mission of the satellite as well as protecting it from this threat.

Once good direct-trajectory antisatellite weapons are developed, protecting satellites will become much more difficult. It is not clear whether a protective system based on maneuvering the satellite out of the way of a direct-trajectory weapon will work against a high-velocity device of this type. It is probably impossible to protect satellites against space-based lasers, either nuclear or nonnuclear. The basic difficulty is that maneuvering will not work because the fire control problem for the laser is simpler than maneuvering the satellite out of the way. Thus, satellites must be shielded against such weapons that will drive the useful-weight fraction of the satellite down to the point of diminishing returns.

The vulnerability of launch systems also must be considered. All US satellites are launched from three sites, two on the

East Coast—Cape Canaveral, Florida, and Wallops Island, Virginia—and one on the West Coast, Vandenberg Air Force Base in California. All these launch sites could be attacked and destroyed by a determined attack from the sea, and such an attack can probably not be prevented if the potential aggressor is willing to pay the price. Thus, all our launch sites are vulnerable, and an aggressor can deny us the "assured access to space" that we must have by executing a relatively simple, conventional military operation or perhaps even a clandestine sabotage mission. The Soviets do not have this problem, because their space launch sites at Tyuratam, Kapustin Yar, and Plesetsk are located deep in the Eurasian land mass. We cannot deny the Soviets access to space unless we are willing to mount a nuclear attack on their launch sites. This fundamental asymmetry between ourselves and the Soviets no doubt makes it harder for us than for the Soviets to maintain military capability in space under all conditions.

The essential conclusion that can be drawn from these considerations is that our current space systems—both the launch capability and the satellites already deployed—are extremely vulnerable to hostile action. This vulnerability is the result of two circumstances: First, the expense of placing weight in earth orbit makes the tradeoff between capability and protection lean heavily in the direction of capability, and second, our coastal launch sites are vulnerable to destruction, so we are denied assured access to space.

A DOCTRINE FOR WARFARE IN SPACE

All military forces operate under "doctrines" that govern their employment. These doctrines are an amalgam of experience, theoretical principles, technical capabilities, detailed understanding of morale and motivational factors, and finally, guesswork. Although such doctrines are imperfect, it is always better to have them than to operate without them. Thus, it is important to develop a sound doctrine for military operations in space and to understand the principles on which the doctrine is based.

For the foreseeable future, the arsenal of weapons designed to shoot down satellites is likely to be more effective than any means to defend them. Thus, the advantage lies with the aggressor who shoots first and brings down the defender's satellite system as part of a general first strike. The aggressor need not initiate a full-scale nuclear attack in order to make the decision to hit the satellite system. Taking out the satellites could become part of a well-defined escalation plan to be executed in the event of a crisis. Thus it seems unlikely that the means for defending and hardening satellites will become good enough to change this situation any time soon, especially if the aggressor is willing to use nuclear weapons.

The problem of protecting launch sites is equally important. For now, the United States must depend on the vulnerable coastal launch sites in Florida and California, which could also be destroyed by an aggressor as part of a first strike. As in the case of the satellites, this first strike need not be part of a general nuclear exchange but could be one step in a series of escalations. As we have stressed, it is much more difficult for us to deny assured access to space to the Soviets. We know, for example, that they have actually launched salvos of satellites either in real crises or as part of a military exercise. They have therefore, as part of their crisis and war plans, a step that includes launching a large number of satellites. Hence, they probably regard assured access to space as an important feature of their wartime military capability.

These are the two central facts around which experts must develop the doctrines to govern warfare in space. One way to protect satellites under the conditions outlined would be to make sure they were not in orbit when an aggressor strikes. The essential idea would be to store the satellites we would want to use in wartime on the ground and to launch them only in wartime or after the military satellites in orbit had been attacked. The proposal envisions the creation of two sets of military satellite systems, one designed for "peacetime" use and the other a "wartime" system designed to survive even a nuclear exchange. The satellites of the "wartime" system would not be launched from the coastal launch sites but rather from protected sites in the continental United States.

PEACETIME SATELLITE SYSTEM

The so-called peacetime satellite system would be designed to maximize the information-gathering capability of the system without regard to survivability. There would thus be no compromise of the ability to provide warning of an attack, to maintain a highly transparent communications system, and to perform surveillance missions. The "peacetime" system is essentially the system we have deployed today. The satellites of this system use the maximum payloads of the highly capable launch vehicles that we now have, including the space shuttle and possibly some upgraded versions of existing launch vehicles such as the Titan, the Atlas, or a launch vehicle derived from space shuttle propulsion hardware.

The peacetime system would take advantage of all the new developments of NASA's civilian space program, including the use of people to enhance the satellite's capability. Ultimately, this would include the use of a space station, first as a possible maintenance base and later for other purposes as well. The space shuttle has already demonstrated a capability to retrieve, repair, maintain, and redeploy satellites in near-Earth orbit. In April 1984, the shuttle crew retrieved a scientific satellite, repaired it in orbit, and redeployed it. Once the space station is built and placed in Earth orbit, missions of this type will become much more common. The development of orbital transfer vehicles, which will follow the space station program, will make similar procedures possible for satellites in geosynchronous orbit. All these operations can be employed to greatly increase the capability of the peacetime satellite system.

A word should be said about the ground stations that support the current satellite systems. These are complex and sophisticated but also quite vulnerable to destruction in a nuclear exchange. Thus, even if the satellites themselves survived an attack, the existing ground systems would probably be destroyed or, at the least, severely damaged. Hardening the existing ground stations against nuclear (or even conventional) attacks would cost many billions of dollars.

The existence of the peacetime system is predicated on the idea that the information provided by the system is most valuable during the crisis that just precedes a nuclear conflict. It is most important to have precise and timely information then so that decisionmakers can determine the proper response to the nuclear attack. It is essentially for this reason that we should not compromise the information-gathering capability of the satellites by using part of the vehicle weight to enhance survivability. The ground-support systems at the launch site and at the ground stations also should be built to have maximum capability, which means that they will be hard to defend.

WARTIME SYSTEMS

The proposed division between "peacetime" and "wartime" systems must start with an examination of requirements. Once a nuclear exchange has occurred, the requirements for information will change and will probably be less detailed than in peacetime. This point is not generally accepted, but it is very important to examine the possible differences between peacetime and wartime requirements. There is at least some reason to believe that the requirements for information following a nuclear exchange could be fulfilled by a wartime satellite system that may be somewhat less capable but also much less vulnerable than the peacetime system. As we have noted earlier, the surest way to fulfill the requirement that the wartime system be invulnerable to an attack in which nuclear weapons are employed is to keep the satellites of the wartime system on the ground, placing them in orbit only after (or during) the attack using a launch system designed to survive an initial nuclear exchange.

The existence of two new, capable solid fuel rockets, the MX missile and the solid rocket booster (SRB) of the space shuttle, offers the opportunity to develop a wartime satellite system that would fulfill wartime requirements. Both the MX missile and the SRB could be kept in appropriate, protected, launch sites at various places around the country and kept there for long periods. The MX missile is a capable space launch vehicle and can place about 5,500 pounds of payload in a near-Earth, 30-degree-inclination orbit; when supplied with an appropriate upper stage, the MX can place perhaps 3,000 pounds in a polar orbit. The SRB, with an appropriate storable upper stage, could have a lift capability more than double that of the MX. The technology exists today to build capable payloads in this weight class for photography and for other purposes. It is also possible to develop a manned "space-plane" in this weight category that could be used for surveillance if all the ground receiving stations and the relay communications satellites used by them became inoperable. (Remember that the Mercury spacecraft weighed only 3,600 pounds.) With current technology, it should be relatively easy to build a manned space plane capable of going into orbit and returning in much the same way the space shuttle does today. These space planes would have a weight compatible with the capabilities of the MX missile and the SRB.

Once a set of payloads of the kind described here is available, they would be placed atop MX missiles and SRBs and deployed to appropriate launch sites. The MX missiles are designed to remain in standby condition for a long time and they could be deployed in existing Minuteman silos. An appropriate storable upper stage would have to be fitted to the SRB. These larger missiles might be deployed in the 54 Titan silos now being vacated as a result of the decision to dismantle the Titan II intercontinental ballistic missile system. The SRB system also can be easily modified to be stored for a long time.

From the outset the satellites of the wartime system would be designed to be much less dependent on ground stations than the peacetime system is. Such designs would include automated systems that would drop packages containing exposed photographic film and other records at predetermined locations in the continental United States at preset times after the launch of the system. In addition, manned "space planes" could be used to provide additional flexibility to the wartime system. This flexibility would be most important under the unpredictable conditions that would exist after an exchange of nuclear weapons.

The employment doctrine of this system could vary with the precise situation, but the most important contingency is clearly a surprise, first-strike nuclear attack on the continental United States. In this case, some of the MX missiles or the SRBs carrying the surveillance payloads would be launched on warning of the hostile attack. In other words, the wartime system would be launched when the peacetime sensors say that an attack is on the way. The wartime satellite surveillance system would then be in place to assess the damage done on both sides by the nuclear exchange.

Alternatively, an attack on the peacetime surveillance satellite system might be declared a hostile act. The response to such an act would be to shoot down the Soviets' surveillance satellite system and at the same time to launch some elements of our wartime system. This is an example of a situation that is less catastrophic than the nuclear exchange scenario, but one in which the existence of the wartime system would still prove extremely useful. In developing the doctrines for warfare in space, many such situations must be thought through in order to determine how best to employ both the peacetime and the wartime systems.

There may be other ways to make the wartime satellite system survivable. It has been suggested that the satellites of the wartime system be stored in distant orbits where they would be hard to find. In the event of a crisis or a war, the satellites would be recalled to lower orbits as needed. Some real advantages would be obtained by employing this method for certain important hypothetical scenarios. The principal problem is that the sensitive methods being developed for the detection of cold asteroids will probably be capable of detecting these satellites as well. Again, the fundamental principle is that there are two separate satellite systems, one designed for peacetime operations and another to be called up in case of conflict.

ARMS CONTROL IN SPACE

Arms control is closely related to the conduct of military operations in space. There are about 10 existing international or bilateral agreements that restrict the placement of various weapons systems in space. By far the most stringent of these treaties is the 1972 agreement with the Soviets that limits the development of systems designed to shoot down ICBMs and submarine-launched ballistic missiles. To the extent that antiballistic missile operations are carried out in space, the treaty prohibits almost all of them except when they are associated with the point defense of certain specified locations. Efforts probably will have to be made to modify this treaty if a really workable system of defense against strategic ballistic missiles is ever to be fielded. However, this treaty does not per se prohibit the deployment of weapons in space when the objective is to destroy other satellites—and that is what we are using the term "warfare" in space to mean in this paper.

Another important treaty is the Outer Space Treaty of 1967, which prohibits, among other things, the deployment of nuclear weapons and "other weapons of mass destruction" in space. (This treaty has been signed by 90 nations.) Thus, antisatellite systems that depend on nuclear weapons to kill their targets are prohibited under this treaty. However, the use of lasers or weapons depending on conventional explosives or kinetic-energy kill mechanisms are not included in the class of prohibited weapons because they are not "weapons of mass destruction." The conventional interpretation of treaties is that anything not specifically forbidden is permitted. The Soviets, for example, have fielded an antisatellite system that depends on "conventional" means to destroy the target without violating the 1967 Outer Space Treaty, which they have signed.

In 1977, the Soviets conducted one of the periodic tests of their antisatellite system. This event prompted President Carter to begin negotiations to prohibit the testing and deployment of antisatellite weapons. Carter took this step because he recognized the critical importance of surveillance and communications satellites to the maintenance of a stable military balance. In 1978 and 1979, the United States undertook a series of negotiations with the Soviets to see whether some kind of an agreement to control antisatellite weapons would be possible. The United States took the position that the Soviets should cease testing their antisatellite weapon. The Soviets argued that the space shuttle (which had not flown at the time these negotiations took place) was a potential antisatellite system, and they tried to put severe restrictions on the operation of the shuttle. Nothing came of these negotiations because neither side would budge from their original positions. The negotiations were terminated when the Soviets invaded Afghanistan in December 1979. After the end of these negotiations, the Soviets proposed to the United Nations, largely as a propaganda measure, a comprehensive "ban" on weapons in space. Meanwhile they have continued to test their antisatellite system. There the matter rests today.

The proposal to divide the military space satellite system into peacetime and wartime components may open some interesting possibilities in arms control. Attempts to control antisatellite systems have failed primarily because no technical means to verify a treaty to stop testing and deployment of antisatellite systems are available. The division into peacetime and wartime systems makes conventional antisatellite systems much less useful, because they would probably have been destroyed or at least severely degraded before the wartime system is deployed. It might be of some value to consider agreements that would, at least to some degree, "protect" the "peacetime" system. The existence of a backup "wartime" system would render the requirement to verify such an agreement much less important. Such an agreement could be based on the provision that was in the 1972 Nuclear Arms Control Treaty (SALT I) which prohibited mutual interference with "national technical means of verification." (This phrase was a euphemism for photoreconnaissance satellites, the existence of which was at that time highly classified.) A treaty could be structured to start with such a provision. Because the 1972 SALT I agreement has now lapsed, this is probably an essential first step.

A second step might be to write some "rules of the road" for the operation of the peacetime system which, to begin with, might require that satellites operated by each side be placed in orbits that would not approach peacetime system satellites closer than some prescribed distance. A "rules of the road" treaty might also deal with the substantial amount of space junk now in Earth orbit. Space junk is debris from launch vehicles, shrouds, fuel tanks, and satellites no longer in use. The North American Air Defense Command now keeps track of about 10,000 piece of space junk, and the space shuttles have been struck by space junk on several missions. Although the situation is not yet dangerous, it will be in about 10 years time if the Soviet and US operations in space continue at the current pace. A "rules of the road" treaty might contain provisions for limiting the space junk that can be left behind in any given launch operation and for ultimately cleaning it up. The proposed rules might be based on certain applicable precedents in international maritime law.

A final step might be to agree to exchange certain data that each side receives from the peacetime systems in order to ensure that political leaders on each side have the same facts on which to base their decisions during crises. All the steps outlined here are small compared with the sweeping public proposals on arms control in space that both sides have made. It is precisely because these steps are small that they may be the best that can be achieved under currently prevailing political conditions.

COSTS AND SCHEDULES

Implementing the proposal to develop a separate wartime satellite surveillance and communications system would be costly and time-consuming. It could cost approximately $20 billion to develop the satellite and to modify the MX missiles and the SRBs that would be used to launch them. Roughly a decade would be needed to implement a full wartime system as proposed. The United States now spends about $16 billion per year on its combined military and civilian space programs. Thus, a 15 percent increase in space-related expenditures would be required to build the proposed wartime system. This is a substantial fraction of the total but the question is really whether any other hardening method would yield comparable results.

The proposed wartime system is the only way to build a space-based information-gathering and communications system that would be secure against what might happen in a nuclear exchange between the Soviets and ourselves. To secure something like the peacetime system that we now have in the operation against the same contingency (the satellites, the launch systems, and the ground stations) would require many times the investment in the wartime system. There is no doubt that satellite system survivability is expensive and time-consuming, but a high degree of survivability must be achieved if the United States is to be fully capable of conducting warfare in space.

THE LUNAR LABORATORY

Edward Teller

Thinking about a lunar colony has occupied science fiction writers for a considerable time. I have been interested in the idea—I hope on a realistic basis—for a number of years. Today, a lunar laboratory seems to make good sense on scientific, technical, and even economic grounds. I have not proceeded beyond general estimates and a few specific points. Details are given partly for the sake of illustration and partly because they may differ from generally discussed ideas.

ESTABLISHING A MINILABORATORY ON THE MOON

What form should such a laboratory take and what projects should be attempted? In the initial stage, only a minilaboratory could be considered. Such a laboratory would be staffed by about a dozen people who would be rotated back to Earth after 3 months' work on the Moon. We know that spending an extended length of time in space leads to decalcification of the bones. On the surface of the Moon, gravitational acceleration is one-sixth that of the Earth, and decalcification might occur at a slower rate than in space.

Lunar laboratory people would have to work inside space suits. Whether a person's bones carry less mass and more gravitational acceleration or more mass (in the form of a space suit) and less gravitational acceleration might not make much difference in providing stresses on their skeletons. People can probably work on the Moon for longer than 3 months without incurring physiological problems. Their stay might last a year: the real limitation may well be psychological.

A few months after Sputnik, I was asked an interesting question about space in a congressional hearings; Should there be any female astronauts? I answered that all astronauts should be women—they weight less and have more sense. Intelligence seems to be better packaged in women. But nowadays, with affirmative action measures, I have to modify my recommendation. Six women and six men should staff the first minilaboratory.

Forty years ago, Oppenheimer talked about a couple of hundred people working at the weapons laboratory. In the end, Los Alamos has a population of 10,000. The lunar base, unfortunately, cannot expand similarly in the near future—gross national product (GNP) will not allow it. However, I dare to hope that the lunar laboratory will have 12 people in 1990 and 100 by the year 2000.

A great deal of material would be required to maintain a dozen workers on the Moon. My estimate is that 20 tons of materials per person would be required each year. Only a small fraction of this weight would have to do with supplying the worker's physical needs for food and water. Obviously, their water would be recycled; this technology is already well developed. The weight of the food required would be a small fraction of the 20 tons, but an energy supply (crucial to their survival as well as to their work) and equipment to conduct their studies would have to be brought from Earth.

The suggestion has been made that we learn to grow food on the Moon so that the colony could be self-sustaining. I do not think this is a good idea. The valuable opportunity of being on the Moon seems wasted in mastering agricultural activities that can be easily accomplished on Earth. Man's development on Earth has been from hunter to farmer to technologist. On the Moon, the first act should be technology, and the very first technology should be transportation. Agriculture can wait until the United Lunar Colonies formulate their Declaration of Independence. Hunters on the Moon seem to be out of luck.

The main expense of the lunar laboratory will be the transportation of material to the Moon each year. This expense induced me to set the size of the lunar colony at 12 people. Flying the shuttle costs much more than was originally expected: each trip carrying 30 tons of payload costs $70 million. Because of the additional rocket fuel required to carry this payload all the way to the Moon, the cost could easily triple.

At a cost of $200 million for 30 tons, the annual expense of transporting 240 tons to the lunar laboratory (12 people times 20 tons apiece) would be $1.6 billion. This figure does not include the cost of preparatory research and fabrication of the materials to be delivered. The development of the preparatory technology (including transfer vehicles) will take about 3 years and several billion dollars. But combining all the expenses (including trips home for the lunar laboratory workers), a total annual budget of $3 billion might suffice. This is not a great sum in comparison with past NASA expenditures.

Scientific and industrial goals could be gained from a lunar laboratory, but the first priority, as I have mentioned, should be transportation. By that I mean creating a refueling station. Even if a few years were required for its establishment, the benefits of a refueling station outweigh all other advantages. By making commuting back and forth much cheaper, the refueling station would make the lunar laboratory much more practical. A refueling capability also would postpone the need for nuclear-fueled rockets. Thus the refueling station is the real basis on which our future space enterprise depends.

FUEL SOURCES

The specific importance of the Moon is that it contains plenty of "green cheese" and all the by-products that one can squeeze out of this material. Of these, fuel for space travel is the most urgent. It could be obtained from either of two sources, lunar rocks and lunar dust. Lunar rocks are essentially oxides. Those oxides should be selected from which oxygen is most easily liberated. Mechanical energy will be needed to crush the rocks so that the oxygen can escape more easily.

Alternatively, lunar dust, called regolith, could be used because it already has the proper physical form. Regolith consists of particles 1 millimeter to 1 micron in size, and covers most of the lunar surface. However, its chemical composition makes it a less desirable source of oxygen than lunar rocks, and mechanical means will be needed to collect regolith in sufficient quantities. Regolith, however, is a good source of hydrogen, present at a concentration of 10^{19} atoms per cubic centimeter in a lightly bound form. The hydrogen is deposited by the solar wind. Thus, fuel for a hydrogen-oxygen rocket could be made available.

Great amounts of energy would be required to get this fuel. Two sources seem obvious: solar energy and nuclear energy. One method of heating the lunar rock would be to focus solar light into a small area using a system of mirrors. Temperatures up to 3,000 degrees Kelvin—which are certainly sufficient—could be achieved. The difficulty in this approach is that the system of mirrors required to reach these temperatures is likely to be heavier than a reactor and therefore more expensive. The question is not whether fuel can be produced but how much it would cost.

The second possible source, a reactor, would not necessarily generate electricity (although this might be done); the reactor would be better used as a source of heat. Transporting the heavy shield for a reactor would be unnecessary; only a specially constructed core of a nuclear reactor would need to be sent. The shielding material could be made of lunar rock. In fact, the whole reactor could be built into a lunar cavity in such a way that it would be well shielded. Lightweight excavation equipment will be essential for this task as well as for several other purposes.

Cooling and maintaining the nuclear reactor present difficult problems. Therefore, if a nuclear reactor were used at all, it should be specially constructed in a simple manner for fuel production alone. The reactor must be safe and sturdy; in case of malfunction, it should be replaced rather than repaired. These problems, of course, require research.

A further requirement is to keep the oxygen produced free of radioactive contamination. Oxygen itself does not give rise to disturbing, long-lived radioactivity, but materials associated with the oxygen do. Methods would have to be developed to eliminate all traces of these. While in principle this should be achievable, carrying it out with remote-control apparatus will not be easy. Experiments to develop appropriate processes would have to be carried out on Earth beforehand, using lunar materials. Liquefaction itself need not be a problem since the lunar nighttime temperature is sufficient to accomplish this process. In the case of hydrogen, a little more effort is needed for liquefaction.

The importance of fuel obtained on the Moon is obvious if one remembers that rockets can be accelerated to a velocity of approximately 4 kilometers per second (km/sec) by fuel comparable in weight to the payload. Each additional 4 km/sec requires a doubling of the fuel. Thus, leaving the Earth (11 km/sec) plus landing on the Moon requires a great amount of fuel; further maneuvers that require fuel become very expensive. Take-off from the Moon (2.4 km/sec) and orbital velocity around the Moon (1.5 km/sec—less than the speed of the Concorde) would be comparatively cheap if lunar-produced fuel became available.

WHAT LIES AHEAD

Thus, the moon could serve as a jumping-off station for exploration of the whole planetary system. One of the great advantages of a lunar colony would be that it would make the whole space program considerably less expensive. Having to bring all fuel from Earth and having to carry the fuel to overcome solar gravity is extremely expensive. Refueling on the Moon would lead to dramatic savings. In the 21st century, laboratories on the other Moons (and eventually on planets) might be established.

One cannot say that the lunar colony would pay for itself in this way, because exploring the solar system will give us nothing except knowledge. This knowledge might provide us with enormous advantages, but knowledge (unless we consider it as intellectual energy and invoke the $E = mc^2$ equation) has no weight.

The step that I would propose after establishing the refueling station would not be to go on to explore the solar system but would be to explore the Moon itself rather than attempting to go on to the solar system. We know almost nothing about the geology of the Moon (a branch of science known as selenology). A little is known about what is a few feet under the surface, and the rest is inference. Obtaining cores down to a few thousand feet will help explore the history of the Moon. Taking corings at greater depths might prove to be expensive and might not be feasible before the year 2000.

Knowledge about crater formation also would be gained. Most craters were probably made by meteoritic impact, but a few may have been made by volcanic eruption. Furthermore, these two phenomena are probably not entirely independent. A large meteor impact may well have effects on the lava layers, which, in some time sequence, show up as volcanic action. The relationship between the maria (the flat "seas" of the Moon) and the highlands (which are full of craters) is incompletely known. The surface mapping that a colony could carry out would be a great improvement over our current knowledge.

In addition to the large amounts of energy required to produce fuel, a lunar colony would need some energy to conduct its work (as well as to survive). One advantage of solar energy, particularly solar electricity, is that it could be made available in widely distributed locations on the Moon. However, if solar cells are used, this energy supply will disappear during the 14 days of solar night except at the poles. Maintaining a continuous supply will require batteries, which are heavy and therefore very expensive to transport. Ultimately however, ways may be found to make batteries out of lunar materials.

Using a thermoelectric source based on the temperature differences on the surface and a few feet below the surface should also be considered. Although the sign of the difference changes, this temperature difference is available day and night.

A few years ago, someone suggested that solar energy should be collected on a satellite, converted into microwaves, and beamed back to Earth for reconversion into electricity. The idea seems unlikely to become economically feasible, but if feasibility can be approached, the Moon would be a better location for the initial conversion of solar energy, because construction materials may become available. Ultimately, however, both solar and nuclear sources of energy should be available. The nuclear source could provide massive amounts of heat; the solar source would offer a modest amount of electricity in areas where special projects might be located.

One important logistical question deserves discussion: Where should the colony be established? I suggest it be in a crater near one of the lunar poles. Three craters close to the south pole appear to be suitable. Craters are scarcer near the north pole. By placing the base near the pole, both sun (and heat) and shadow (and extreme cold) are within easy access. Similarly, from such a point, Earth can be seen, which is useful for communications, yet nearby one is shadowed from Earth, a preferable situation for astronomical observations.

The contour of the crater would offer additional flexibility; because of the periodic intense radiation produced by flaring sunspots, lunar laboratory workers will need considerable, readily available shielding. If the laboratory were built in a sort of inverted L-shape over the edge of a crater, the workers would have a quick means of ducking into a shadow.

The best place for living quarters is inside a cave in one of the craters near the lunar pole. The temperature there is not extreme, because an average of the lunar day and night temperature prevails inside a cave. Locating the living quarters in a cave would save energy and protect the colonists against unusual levels of solar radiation. Thus, starting from the south pole during the safe period of sunspot minima when no solar flares are expected, the colonists could explore the lunar surface.

Perhaps the most unexpected advantage of a lunar laboratory is its economy. Having spoken of $3 billion in expense, this may seem improbable. However, remarkable possibilities in pure research as well as economies in defense spending and industrial applications make the enterprise appear promising.

One vital need in avoiding a nuclear war is to know if any rockets are launched on earth. The best observation satellites—our eyes in the sky—could be located in synchronous orbit at about seven Earth radii above us. The question of how to defend this extraordinarily vital link in our defense system is difficult. One expensive but effective proposal to defend these observation satellites from laser attack and from x-rays resulting from a nuclear explosion is to put a heavy shield—a lot of mass—around them. No matter what the material is, its mass would be useful, although its transportation would be expensive.

The strange point is that this strategic location—the synchronous orbit—is less expensive to reach from the Moon than from the Earth. The velocity change needed to get into synchronous orbit starting from the Moon is one-fourth of the velocity change required for a start from Earth. Starting from the Moon, the needed fuel weighs less than the payload, whereas starting from Earth, approximately 10 times as much fuel as payload must be boosted into space. Thus, if energy on the Moon becomes available, the expense of putting protective materials around satellites could be greatly decreased if the project were undertaken from the Moon, using lunar rocks.

INDUSTRIAL APPLICATIONS

Let us turn to industrial applications. Some time ago, I proposed that NASA should adopt as its theme song, "I've got plenty of nothing—nothing's plenty for me." Indeed, an obvious use for the lunar laboratory is connected with "nothing"—that is, a cheap and excellent vacuum. What sort of vacuum does the Moon have? At this time we can not know accurately because the astronauts obviously contaminate their immediate surroundings. The lunar colony itself may contaminate the vacuum, but I suspect that it will not have an appreciable effect. The Moon itself is emitting gases. Intense ultraviolet solar radiation, the micro-meteoric impacts, large meteor impacts, and volcanic events all disturb the vacuum.

Because the escape velocity from the Moon is about 2.4 km/sc, however, the lunar noontime temperature is sufficient for oxygen to escape. Heavier gases will escape more slowly by diffusion. The atmosphere of the Moon—what there is of it—will rotate with the Moon. During the 14 days of lunar night, it will experience extreme cold, and condense. With the sunrise, the gas will again evaporate, rise, and diffuse to the dark side, which will act as a trap. The lunar motion will sweep the atmosphere toward sunrise, and the sun itself will push the atmosphere back into the presunrise area. Whatever gas there is will be concentrated on one moving longitude—a longitude around the dark edge of sunrise.

Measurements of the moon's atmosphere should be conducted in this area. The pole itself would be quite interesting because the permanently shadowed regions there might accumulate some material. This is the most likely place for water to be found; a discovery of water deposits would, of course, change many considerations. The best way to obtain fuel for propulsion would then clearly be through electrolyzing water, using a substantial nuclear reactor or, more probably, an appropriate solar source of electricity. Thus far, however, the search for water on the Moon has proved futile.

Discovering the quality of the vacuum on the Moon would have to be done by remotely controlled experiments. The search for the best vacuum could be conducted anywhere except near the edge of sunrise. Should the Moon prove to have an excellent vacuum (which is probable), surface chemistry could develop from an art into a science. Everyone knows that breaking a material into two parts is an irreversible process. The basic reason is that breaking occurs irregularly and the parts no longer fit exactly together. However, even when the parts do fit, for example, in the case of carefully broken graphite or mica that come apart in molecularly plane surfaces, the flat surfaces can not be made to adhere again even in the best vacuum obtainable on Earth. The reason is that before the two pieces are brought into contact, a monomolecular layer of impurities forms on the sheared surface and destroys the possibility for fully effective adhesion.

The Moon may possess a vacuum approaching that of interplanetary space—about 1,000 molecules per cubic centimeter. Breaking mica, putting it back together, and registering the degree to which it adhered might be an extremely primitive but effective way to detect an excellent vacuum. Surface chemistry is of great importance in electronics. The availability of an excellent vacuum on the Moon might lift electronics to an entirely new state of perfection and thus enable a lunar laboratory to pay for itself. The kind of computing machines discussed by Dick Feynman might first be produced on the Moon. A first step toward making such a machine would be to learn more about surfaces.

Some of the early projects for the lunar base would involve making astronomical observations. The observatories in space currently include excellent mirrors composed of small plane elements, finely adjusted electronically. I suspect that such a telescope placed on the Moon would be even more effective. One advantage is that mirrors on the Moon can be completely shielded from the Earth and the sun. Moonquakes tend generally to be much smaller than earthquakes and would present few difficulties for adjustable mirrors. The major difficulty is that the temperature change between lunar day and night would necessitate careful construction and readjustment of the mirrors unless the mirror were located in a permanently shadowed region near the pole.

The most exciting aspect of lunar and space observations, of course, is that they are in technicolor. Not only the single octave of visible wavelength is registered, but all wavelengths—gamma rays, x-rays, ultraviolet, infrared, and all radar and radio emissions—are easily observed from the Moon. Observations of the sun would also improve, because both the atmospheric interference and the perturbation from the noise originating in our radio emissions would be eliminated.

To me, astronomy is a most remarkable science. Although this branch of science has received limited funding, the recent progress made in astronomy is at least as great as that in any other part of physics. For example, quasars, pulsars, and neutron stars are beautiful and radically new discoveries. The lunar colony, by putting some effort into a study of our own galaxy and of other galaxies, might well improve our knowledge of the origin of the universe. Such basic information is scarce, and the difficulties of finding out more are enormous. This work is related to the kind of knowledge in which public interest is the greatest.

The last application of the lunar laboratory that deserves mention is its potential enrichment of the study of high-energy physics. At present, cosmic rays, which have exceedingly high energies, are not being used for exploratory purposes. By the time these extremely energetic particles reach the Earth's surface, they are contaminated by interaction with the atmosphere. The best way to begin collecting observations from particles of 1,000 or more gigaelectron volts would be to dig long collimating holes on the Moon. Although the frequency of events would be low, the chance of seeing interesting events would be a certainty.

One final high-energy physics project deserves consideration: putting an accelerator on the Moon. Such an accelerator would consist of separate accelerating units of some length and curvature with some free runs for the particles between them. Because of the small size of lunar quakes and the general cleanliness of the environment, construction of such an accelerator is a real possibility. The problem would be to provide deflecting elements, which are heavy. If this could be done using lunar materials—for instance, using cobalt to construct the deflecting structures—a wonderful accelerator could be constructed. It is easy to imagine such an accelerator on the rim of a big crater.

This suggestion allows me to talk about one man who lives on in the minds and hearts of many of us here, Enrico Fermi. Fermi, it is said, never showed a slide in his life, and I have tried to emulate that practice. But Fermi did show one during a talk he gave on accelerators and their probable development; Fermi's slide showed an accelerator encircling the earth. I don't believe that this will ever become reality, but our colony on the Moon might conceivably build such an accelerator during some dark lunar night.

Dr. Hans Mark, the deputy administrator of NASA, estimated (in an analogy with the population of Antarctica) that by the year 2030 the lunar colony might have 10,000 people. Even with the development of refueling on the Moon, the expense of such a colony could approach $1 trillion per year. If we can avoid a major war in the next half-century, the cost might be less than 3 percent of our GNP at that time.

Would such an effort be reasonable? In view of the great and varied benefits, of which we can now see only the very beginnings, I would not hesitate to agree with Hans Mark's projection.

THE ROLE OF SPACE IN PRESERVING THE PEACE

William Howard Taft IV

In the coming months and years, America's leaders—including many of you present here today—will be making decisions about our role in space that will have effects reaching well into the next century. We must draw on your experience if we are to meet the enormous technological and policy challenges that await us.

Before we look forward to our hopeful future among the stars, I want to talk about a moment of hopelessness in our national past. Let's go back 43 years, to midday on this date, December 6. A large naval task force was steaming from the west towards the Hawaiian Islands. Under the cover of the weather, that armada bore down swiftly on the unsuspecting islands. In the early morning darkness of the next day, the Japanese carriers launched their aircraft. They struck at dawn, with *total surprise,* at Pearl Harbor. The result, of course, is well known to us all: the near-total destruction of our Pacific fleet and the loss of many brave men—a day that, as President Roosevelt said, would live in infamy forever.

Why, we ask, was the element of surprise so decisive on that day? Why did the lack of intelligence, or the failure to pay attention to whatever information was available, cause us to endure such terrible losses?

I think the answer is clear. We are a *defensive* nation. Our purpose, our goals, our hopes—all relate to peace. We don't start fights, and we don't look for trouble. Consequently, we must always remain alert and protect ourselves from those who do not share our love for peace. Unfortunately, it takes reminders such as the carnage of Pearl Harbor to jar our peaceloving nation back to reality, the reality that we live with in a world not of our own making.

Pearl Harbor was long ago and some would argue that we now live in a world totally different from that of 1941. Today, for example, our satellites could easily pick up that aggressor fleet bearing down on Hawaii. Global communications, relayed through satellites, would allow us to sound an instant alarm. The rush of technology is so rapid, the changes so accelerated, that we sometimes assume that any problem we can envision can be almost routinely addressed and solved by some combination of our brilliant scientific and engineering capability and our industrial and technological might.

I truly wish it were that easy—but with opportunity has come challenge. Today, more than ever before, the United States can not afford to be surprised because the world might not survive the consequences of a modern-day Pearl Harbor. Today, the velocities that aircraft and weapons travel have effectively shrunk this globe of ours. A devastating attack can be launched from anywhere, and to anywhere, in the world quite literally in minutes.

In this world of vastly compressed time and space, and thus of greatly reduced warning and reaction times, we have turned to the heavens to preserve the peace. From space we obtain a degree of omniscience, observing the position and movement of all forces that might threaten us—including, of course, the offensive strategic missiles of the Soviet Union. Space systems enable our pilots and seamen to navigate and our leaders to control and communicate with their forces. In short, we can no longer ensure the safety and security of our nation without our systems in space.

What is most amazing is that such a significant degree of dependence on this newest frontier has occurred at a time when man himself has only put his big toe in the cold and unknown water of outer space—we have still only stepped on the shores of the cosmic vastness. I believe that the future will see a great expansion in the uses of space, not only by the Soviets and ourselves, but by other nations as well. Space will play an increasingly significant role in the security of *all* nations.

How then does a defensive nation, whose prime concern is preserving the peace. prepare for such a world? A prudent national security policy for confronting the uncertainties of the future must have two components: *strength* and *vision.* As President Reagan has said so well, "Tyrants are tempted by weakness." With that in mind, he has put forth a defense program that has been rebuilding the strength necessary to deter tyrants now and well into the future.

As regards the relationship of our space policy to the second component in that formula for peace, vision, we clearly see that vision in the national space strategy set by President Reagan this past August. The strategy sets priorities and directions for all aspects of America's participation in space—civil, commercial, transportation, and national security. I now turn to a few aspects of what we are doing in the Defense Department to put that strategy into effect.

First, I want to speak about an example of President Reagan's vision that has already left its mark on history, his challenge to the Nation to find a way to harness technology in the cause of peace and to free mankind from the terror of nuclear ballistic missiles. We are now embarked on the research program that General Abrahamson discussed with you this morning, the Strategic Defense Initiative (SDI).

We can bring the president's vision to reality only if we have the full support of all the groups represented here today—the scientific, industrial, strategic, government, and military communities. So I want to discuss how our strategic defense initiative complements our dual policies of *deterrence* and *arms reductions.* We have carefully designed SDI to strengthen deterrence and to enhance the opportunity for genuine, verifiable arms reductions. We can now look to the day when we can replace our sole dependence on offensive forces for deterrence with a more stable deterrent based on effective strategic defenses as well ... when we can deter war by being able to destroy weapons, not people.

Some skeptics claim that a strategic defense system must be guaranteed 100 percent leakproof before it can be considered a worthwhile national goal. But to prove the potential of a defensive deterrent, the first goal of SDI research, we need only show that we can make the outcome of any attack so uncertain that an adversary would not hazard aggression.

Even a 90 percent reliable defense can be a 100 percent effective deterrent. No rational aggressor is likely to contemplate nuclear conflict when the ability to penetrate our defensive system and destroy our retaliatory capability remains uncertain. In the case where the irrational does occur, through the failure of deterrence, an accident, or a launch by some unstable government, defenses would offer the *only* hope of protecting our people.

Just as the Strategic Defense Initiative can strengthen deterrence by reducing the military utility of nuclear ballistic missiles, it can also enhance the opportunity for arms reductions. For by devaluing nuclear ballistic missiles, we can create powerful incentives for sharp reductions in their numbers—reductions that would enhance the security of the United States, its allies *and* the Soviet Union.

Those who claim that the SDI program will violate the Antiballistic Missile (ABM) Treaty do not understand the ABM Treaty or our program. (The treaty permits research, and SDI is a research program.) Nor do these people recognize that the Soviets have been conducting similar research since the late 1960s. They ignore the fact that the Soviets have long had an ABM system deployed around Moscow, a deployment perfectly legal under the treaty, and that the Soviets are constructing a major early warning radar facility of a type and in a location forbidden by the ABM Treaty.

In view of those facts, our Strategic Defense Initiative is a prudent hedge against a surprise that could be far more devastating than Pearl Harbor—a sudden Soviet breakout from the ABM Treaty. By pursuing President Reagan's quest today, we will provide some future president and Congress with an option to protect our people and our allies by deploying a strategic defense system that would enormously enhance stability and the safety of the world.

In the meantime, as we work toward that important goal. we must stay on the course we have now set. Deterrence can continue to maintain the peace in the face of a continuing Soviet buildup only if we restore the nuclear balance. Arms reduction negotiations will yield the results we want only if the Soviets have an incentive to reach agreements. This is why we must continue with our strategic modernization program to rebuild our nuclear deterrent, and, most particularly, why we must deploy the MX to strengthen the land-based leg of our strategic triad.

Just as President Reagan has demonstrated strategic vision in committing us to the Strategic Defense Initiative, we in the Defense Department understand that we must also have the vision to prepare ourselves for all the challenges of space, to look beyond today's bureaucratic, tactical, and technical strictures. I think we have made a good start, but we still have some perplexing questions to answer. Because we depend on you to help us find some of these answers, I want to give you a brief progress report.

Organization.

Just a week ago, Secretary Weinberger announced that we are forming a unified command for space. It will help assure full service coordination and cooperation as we push out across the frontiers of space, just as our other unified commands join together our forces working in theaters around the world.

As General Abrahamson told you this morning, his Joint SDI Program Office allows us to obtain a similar unity of effort with research and development for strategic defense. And each of the services is consolidating its efforts in similar ways. When the Air Force organized its Space Command, for example, it found that 20 different agencies were involved in programs related to space. Space is simply one more dimension in which the Defense Department has found that the whole is equal to many times the sum of its parts.

Hardware.

While we are unifying organizations as much as possible, we are also trying to incorporate a prudent amount of redundancy into the systems we build for our space efforts.

Because we can no longer afford the vulnerability of having a single facility in California control all our satellites in orbit, we are building a second space operations center at Colorado Springs. For similar reasons, we are supplementing the shuttle facility at the Kennedy Space Center with a West Coast spaceport at Vandenberg Air Force Base. We plan to develop a new, expendable launch vehicle capable of handling the vastly larger payloads we will require in coming years. This will end our dependence on one manned launch vehicle, the shuttle.

Besides increasing redundancy, we are taking a variety of other measures to reduce the vulnerability of our satellites: hardening, developing a maneuvering capability, and selecting orbits for maximum survivability. The overriding principle guiding our improvements is that the survivability of our space assets must be commensurate with the importance of the support they provide. Because that support has become essential to our national security, you can be sure that survivability will remain a top priority.

The final point I want to make about our hardware is that it must be affordable. Science may show us how to make great leaps beyond earlier technological limitations, but such advances will have dubious value if we haven't faced up to very real fiscal limitations. Take, for example, the expanding costs of launches. If we can't bring those costs down, we will soon have insufficient funds to invest in the real payoffs of space: the operating space systems.

People.

Although organizational and technical considerations are important, the critical variable in the national security equation during the space age will be the same as it has been throughout history, people. The technical challenges and the uncertainties of operating in outer space will call for men and women of great competence and extraordinary dedication. We must attract such people to our ranks. Then we must train them and help them grow, so we stay at least one step ahead of the rush of technology.

We have only begun to confront those human challenges. For example, the Air Force Academy recently established a space degree program for its cadets. But *all* the services must reexamine their educational and training programs carefully and determine how they can better prepare themselves for the Nation's increasing involvement in space. Indeed, our entire national education system needs to recognize that the youngsters in grade school today will be America's pioneers in outer space.

Yes, we need to build on America's strengths: the industriousness and ingenuity of our **people,** the technological superiority of our **equipment,** the efficiency and vitality of the **organizations** that characterize a free society. We need to nurture those strengths as we push back the frontiers of space. And we can expect, as did those who explored earlier frontiers, that we will face tremendous obstacles and difficulties.

But space, like most frontiers, provides hope and opportunity. If America is to surmount the still undefined obstacles and realize the hope of peace and the opportunities of space, we must have people of vision leading us into the unknown. And we are encouraged that you have joined us today to help chart that course.

LIVING OFF THE LAND—
The Use of Resources in Space for Future Civilian Space Operations

Gregg E. Maryniak

The principal barrier to space exploration and development is the cost of launching materials and personnel from the surface of the Earth into orbit. This seemingly inescapable barrier can be overcome by using resources already in space for propellants, shielding, life support, and construction. This paper examines the sources and types of nonterrestrial materials, the tools and techniques already under development to harvest space resources, and the ways in which these resources can be used to extend the scope of space operations.

In the Apollo era, manned space flight was characterized by brief missions. All consumables such as propellants, oxygen, and water for the entire mission were carried up from the Earth in the spacecraft. This remains essentially the case today, although some shuttle missions will use solar cell arrays to take advantage of abundant solar energy in space and to extend their stay on orbit, using this local source of electricity instead of generating power by consuming hydrogen and oxygen in fuel cells.

The decision, announced by President Reagan, to proceed with a permanent space station marks the beginning of a new phase of space operations. In light of this commitment, it is appropriate to consider new sources of material and energy resources for space operations. Specifically, we shall examine the

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role of resources already in space to support and enhance operations in cislunar space and on the surface of the Moon.

The concept of using indigenous sources of supply during the exploration, pioneering, and colonization of new territory is found throughout the history of human exploration. Early seafarers would make periodic landfall during their voyages of exploration to take on fresh water. Frontiersmen in America "lived off the land" for long periods of time. Early settlers transported only tools and other valuable items such as nails to their final destinations. To avoid the cost of transporting more traditional (and more highly processed) building materials, they made ingenious use of materials such as logs, earth, rocks, and other locally available products. Arguably, the use of locally available resources enabled the rapid development of settlements and accelerated the rate of growth of roads, sawmills, simple forges, and other key elements of colonial infrastructure.

RATIONALE FOR THE USE OF SPACE-DERIVED RESOURCES

The principal obstacle to opening the new frontier of space is the cost of transportation. Space transportation differs from the terrestrial transportation modes that we intuitively understand. For a given mode of earthly transport such as rail, sea, or air, the cost is roughly proportional to the distance traveled. Indeed, prices are often quoted in cents or dollars per mile. In space transport, the key question is not what distance must an object travel to get to a desired destination but rather what changes of energy are required to get a given payload to the required location. For space transportation away from a planet's gravity, the formula for propellant required is a simple function of the velocity change needed ("delta V") and the exhaust velocity of the rocket.

To launch a payload from the surface of the Earth so that it will "escape" the Earth's gravity, it is necessary to impart a velocity change to the payload of 11.2 kilometers per second (km/sec). Rockets achieve this change of velocity (delta V) by expelling reaction mass in the form of gases heated and expanded by the energy contained in the chemical bonds of stored propellants. Launching from the Earth requires high thrust to counter the pull of the planet's gravity; the vehicle's structure must be designed to withstand both high accelerations and loads imparted by atmospheric pressure. All the fuel for the flight must be lifted at launch, and that used in the final seconds of powered flight must be accelerated to a velocity nearly that of the payload because the last unit of fuel will be used to accelerate the entire remainder of the payload. The fuel, tankage, engines, and structure weigh so much that a typical payload will constitute only about 1 percent of the vehicle's weight at launch. Even a sophisticated system such as the space shuttle has a payload to low Earth orbit of about 1.5 percent of launch weight.

The difficulty of accelerating payloads into space from the surface of the Earth is the primary reason for the high cost of space operations. Although advances in propulsion, structures, and methods of fleet operation will decrease the cost per pound of cargo delivered to Earth orbit, the 11.2-km/sec escape velocity will remain a permanent law of nature.

In an article that appeared in the September 1974 issue of *Physics Today*, Dr. Gerard K. O'Neill, professor of physics at Princeton University, proposed a means of getting around the seemingly inescapable problem of building large, useful structures in space, given the high cost of launching materials. O'Neill's solution was to find a source of materials for space construction "closer" to the construction site in space than the Earth, not in terms of distance but rather in terms of the delta V required for delivery. O'Neill's proposal was to use material from the Moon for space construction. In comparison with the 11.2-km/sec escape velocity of the Earth, the Moon's escape velocity is only 2.4 km/sec. Since the energy of a moving object is proportional to the square of its velocity, the energy required to launch a payload into space from the Moon is 22 times less than that required to launch the same payload from the Earth.[1]

O'Neill also suggested that the lack of an atmosphere on the Moon, coupled with the fact of lower energies required for launch, made it possible to launch material from the Moon without the use of rockets. He detailed the parameters for an electromagnetic catapult that has come to be known as a mass-driver. The mass-driver is a special type of linear motor which accelerates small packets of lunar materials to lunar escape velocity. As the packets leave the mass-driver, their velocity is measured and later precisely adjusted so that the packets can be captured at a collection point in space. Whereas a typical rocket lifting material from the Earth delivers a payload of about a hundredth of its initial weight, a mass-driver on the Moon can launch about 60 times its entire weight per year. Mass-drivers, once implanted on the lunar surface, would require no chemical fuels that would need to be imported from the Earth. They can be powered by electricity from solar cells or other sources. Unlike most rocket systems, the mass-driver is completely reusable; only the payload would be released into space.*

HARVESTING LUNAR RESOURCES

Let us now follow the process that a quantity of lunar soil would undergo in the scenario just proposed. It is high noon at the lunar base (and will be for another 10 Earth hours.) Under the general supervision of a human operator in Chicago, a semiautomatic tractor scoops up a shovelful of lunar soil and dumps it into a towed hopper. The soil contains almost 40 percent oxygen by weight, with another 30 percent in metals such as aluminum, iron, and titanium. The vehicle follows a preprogrammed path within the shallow pit that comprises the lunar mine. In the event of an encounter with a rock too large for its scoop or any other problem, the vehicle signals its human operator on Earth for assistance. The 3-second roundtrip signal delay is not a serious inconvenience for most operations, and the teleoperated tractor is equipped with a fast-response automatic

*Several mass-drivers have been built by members of the Space Studies Institute. The latest model achieves an acceleration of over 1600 g's.

sensor that halts it immediately if it encounters an obstacle that could damage the machine.

The now-full hopper is towed toward the several soil-covered shuttle external tanks that make up the Moon base. Here the soil is compressed and sintered in spherical payloads about the size of a baseball. Each payload is then automatically loaded into a "bucket," the only moving part of the mass-driver. The bucket corresponds to the armature of a typical electric motor. In the mass-driver it holds the payload of lunar soil as it flies down the length of the machine. The bucket contains a coil of wire into which a current is induced. This creates a magnetic field that acts as a handle for the drive coils of the mass-driver. The tube of the mass-driver is made up of drive coils, each about as wide as a dinner plate. Each drive coil in turn pulls on the bucket coil, sending it through the device. The bucket interrupts light beams as it travels, triggering the silicon-controlled rectifiers which gate power to the drive coils. The drive coils not only accelerate the bucket through the machine but also exert a powerful centering force that prevents the bucket from contacting the sides of the mass-driver tube.

At an acceleration of 1,800 gravities, the bucket travels the 525 feet of the acceleration portion of the mass-driver in one-eighth of a second. The packet of lunar material is released from the bucket and begins its unpowered coast into space. The now empty bucket enters a deceleration section, which is a reversed version of the first portion of the mass-driver, a generator instead of a motor. As the bucket continues its flight, its kinetic energy is converted back into electricity and the now-slowed bucket is returned to the starting point for another load.

Down range after 1 minute of flight, the payload interrupts an array of laser beams. Its speed and direction are thus precisely measured. A small correcting station applies electrostatic forces to the packet to precisely trim its speed and direction of flight. The packet is now part of a stream of similar payloads launched continually during lunar day by the solar-powered mass-driver. The pull of lunar gravity gradually slows the packets. Their destination is a large cylindrical structure located about 63,000 km from the Moon. The cylinder, whose far end is closed, catches the payloads. When several thousand tons of material have been accumulated, the cargo is moved by a low-thrust space tug to a chemical-processing plant.

The processing plant can be in high orbit around the Moon or the Earth. In either case, the orbit will be selected so that the plant receives 24 hours of solar energy every day. The constant availability of energy at these locations is a key reason that most of the processing of lunar materials (except those destined for use on the Moon's surface) takes place in space. The amount of energy used per unit mass of throughput at the processing plant may be high by terrestrial standards, but that energy comes from the free sunlight. The plant will have one important design constraint unique to space processing: it will be designed to minimize the use of consumable chemical reagents, particularly those that have to be supplied from the Earth.

The output of the plant will include metals in the form of sheet and bar stock, silicon for solar cells and composite structures and oxygen for use in propellant, atmosphere, and water production. Slag can serve as radiation shielding. Apart from the intrinsic value of these commodities, they will be extremely valuable by virtue of their position in free space, from which they can be readily delivered to customers in orbit at much less than the cost of similar materials launched from Earth.

REFINEMENTS OF THE BASIC CONCEPT

The concept of using lunar material launched into space by the mass-driver as described by O'Neill was studied extensively in NASA-sponsored summer studies during 1976[2] and 1977.[3] Both studies confirmed the technical feasibility of constructing large structures in space from nonterrestrial materials. The results of these studies were further confirmed by research conducted by a variety of NASA contractors. Chemical processing of lunar materials was studied by Criswell under the auspices of the Marshall Space Flight Center.[4] In work performed for the Johnson Space Center under two separate contracts, the use of nonterrestrial materials for construction of solar power satellites

(SPSs) for importing electrical power to the surface of the Earth was studied and found to be economically beneficial.[5]

Several of these studies included, in a limited way, the concept of "bootstrapping," that is, the use of space resource and manufacturing facilities to produce additional mass-drivers and processing and manufacturing equipment to attain rapid exponential growth within the capabilities of the space shuttle and shuttle-derived launch vehicles.[6] The second NASA summer study found that the investment cost to reach 630,000 tons per year (worth about $20 billion *annually* in the form of SPSs) would be about $30 billion if mass-drivers were used as reaction engines for interorbital transportation.

The minimum investment necessary to begin rapid exponential growth in space was reduced by about one order of magnitude by a further study conducted during 1978 and 1979 under the auspices of the Space Studies Institute.[7] (The institute was formed in 1977 to ensure the continuation of research into the use of space resources.) Through a series of workshops, the institute sought to define more precisely the minimum size of a facility to process lunar materials into feedstock for industry in space. The results of the workshops were published in an article entitled "New Routes to Manufacturing in Space".[8]

The workshop groups used a set of conservative assumptions; these included using only present-technology, low-hydrogen rockets for all interorbital transport. Unmodified shuttles (that is, no shuttle-derived heavy-lift vehicles) would be used for Earth-to-orbit transportation. No part of the system would use a greater degree of automation than that now used in some automobile–manufacturing plants.

The group concluded that it would not be economically effective to push for totally automated systems. Human repair crews appear to be assured of a billet in future space projects. Although a number of studies have investigated the concept of self-replicating machine systems for use in space,[9] analysis of representative production equipment led the group to conclude that not all the space system would be self-replicated. Particularly in the initial stages of development, it makes more sense to construct the large, simple, and repetitive components of industry on site and to import the computers and precision parts of machine tools from the Earth. Initially, 95 percent of the mass of the system would be replicated in space, and that percentage would increase as space industry matures.

Using the same basic set of assumptions, the group analyzed five detailed scenarios for the buildup of industry in space. Three of these appeared particularly attractive:

Case 1 called for a manufacturing facility manned by three crew members on the surface of the Moon. Its products would be transported into space using chemical rockets. The initial production rate would be 240 tons/year with a 45-day doubling time for the production rate. Fifteen shuttle flights would be needed to set up the system, and two more shuttle flights per year would be required for crew support. This system would cost approximately $5 billion.

The Case 1 system is effective for the rapid buildup of lunar products (such as mass-drivers) on the Moon but is inflexible in terms of products delivered to high orbit. Even with the use of lunar oxygen, its transport costs are much higher than those of a lunar mass-driver.

Case 2 consisted of a fully automated manufacturing facility that would be visited occasionally by repair crews. Again, the product would be transported by chemical rocket. The system would consist of 15 one-ton modules with automatic equipment that would be supervised from the Earth. The system would have an initial production rate of 80 tons per year with a 90-day doubling time. Fifteen shuttle flights would be required for implementation. This system was estimated to cost about $3 billion.

Although Case 2 was the least expensive system studied, its range of products was less versatile than the other two cases and its growth potential was limited to producing only simple metal components over a long period of time. Furthermore, its high level of automation made it the most extreme case in terms of required technology development, and the group thought that its research and development cost estimate was the most uncertain of the three cases.

Case 3 consisted of a system similar to that described earlier in this paper, using a mass-driver for launching material into space from the Moon. The Case 3 system differs from earlier studies by NASA and others in the use of automation and teleoperation from the Earth, smaller start-up size, and high degree of self-replication. This system would consist of a manned facility on the Moon initially weighing 107 tons, which would operate a mass-driver launcher and would also replicate mass-drivers. An additional 89 tons of system in the form of a mass-catcher and a space manufacturing facility would be deployed in space. With the solar-powered mass-driver operating only during lunar days, the system would have an initial production of 1,800 tons/year; doubling time would be 90 days. This system appears capable of bootstrapping itself to a production level of 100,000 tons/year after 2 years of operation. Implementation of the system would require 36 shuttle flights plus two additional flights for crew support per year. The R&D and deployment estimate for Case 3 was $6 billion.

Case 3 combines high through-put, conservative technological requirements, and a wide range of products in space. The investment required is in the range of large private ventures such as North Sea oil rigs (up to $2.6 billion each); the Alaska pipeline ($7 billion); and the Churchill Falls, Quebec, hydroelectric power system (approximately $10 billion).

PRODUCTS FROM LUNAR MATERIALS

The end products of a system such as that just described would be a variety of consumables, building materials, and feedstocks for space-based industry. These products would range from completely unprocessed lunar soil to such refined products as solar cells, SPSs, and large space habitats.

At the lowest end of the processing spectrum is the use of completely unaltered lunar soil for use on the surface of the

Moon or in free space. Certainly one of the earliest uses of this material would be for radiation shielding. In high orbit, raw lunar soil would probably be used for initial shielding requirements. As the space industry matures, raw lunar soil would probably be supplanted by the slag and other waste products that remain after processing out the useful oxygen, metals, and silicon at the space manufacturing facility.

Another use of lunar soil on the lunar surface would be in site preparation. Inorganic polymers based on silicon could be added to stabilize the raw soil.

Raw lunar soil may also be used as reaction mass for deep space missions. The use of mass-drivers as reaction engines appears to be extremely cost-effective for transfer of bulk cargo.[10] Ultimately, these long, spindly spacecraft will use oxygen as reaction mass. Oxygen has the advantage of being easy to handle and store. Once released, it simply boils off to the molecular level and therefore poses no hazard to future navigation. Because oxygen is abundant in lunar soil, the cost will drop significantly as space manufacturing progresses. At some point it might even be regarded as a waste product. However, before this point is reached, raw soil might well be used as reaction mass in mass-driver reaction engines, particularly for deep-space missions.

On Earth, we are accustomed to having an atmosphere and large masses of water to use as a heat sink for industrial processes. In free space, however, waste heat must be dissipated by radiation. Radiator mass can be a costly part of large space systems. Henson and Drexler have suggested that a large portion of the mass of such radiators might be made up from lunar dust entrained in a low-pressure gas.[11]

Sheppard has proposed making a form of lunar concrete using raw lunar aggregate (unprocessed except for sizing) contained in a fused-rock binder.[12] NASA recently approved the allocation of 40 grams of lunar material to Construction Technology Laboratories for use in experiments in making hydraulic concrete for space construction.[13]

Another lunar material that may be useful with a minimum of processing is basalt. Processed basalt is already manufactured in Europe and the United States. Cast basalt can be used to fabricate pipes, tiles, plates, and fittings. Sintered basalt can be used in nozzles, wire-drawing dies, spheres, and other small articles. It can be machined or turned into a fiber for composite structures.[14]

Fiberglass made from lunar materials will find many applications in space manufacturing, such as electrical insulation, structural panels, tubing, and incombustible fabrics. Designs for fiberglass plants for use on the Moon (including a furnace insulated with lunar soil) and in space have been proposed.[15]

One of the most interesting products available from lunar soil without chemical processing is iron. Free iron (combined with nickel) exists as fine particles distributed through soil at the lunar surface. These particles are the result of meteoric impacts and the reduction of lunar silicates by solar wind hydrogen. Agosto has described a system, assembled from "off-the-shelf" components now commercially available, that could process 184 kilograms of metals per hour. At this rate, the system would process metals equivalent to the mass of the system every 203 hours.[16] In addition, the availability of free vacuum and the availability of the metal as a powder would make it easy for the material thus recovered to be fabricated into metal parts using a technique called powder metallurgy. In this technique, metal powder is placed in a mold and heated and compacted so that the particles flow together. This technique makes it possible to fabricate precise components with a minimum of machining.

OXYGEN FROM THE MOON

One of the most useful end products from lunar resources would be oxygen. Oxygen constitutes nearly half of the weight of lunar soil. Aside from its obvious utility as the most important component of a breathable atmosphere, it makes up 89 percent of the mass of water. Its use as reaction mass for interorbital and deep-space missions in vehicles propelled by mass-driver reaction engines has already been discussed. It may also be used in future ion-engines for the same purpose. Chapman has proposed using lunar-derived oxygen as a propellant in laser-propelled vehicles for low-acceleration transport between the surface of the Moon and lunar orbit.[17] Oxygen may also serve as a working fluid in heat rejection systems.

From the standpoint of economics, however, the most important use of lunar oxygen would be to reduce the cost of space transportation. For the near future, most of the propulsion needs of cargos traveling beyond low Earth orbit will be met by chemical rockets using oxygen as an oxidizer and hydrogen as fuel. By weight, the ratio of oxygen to hydrogen is about 6 to 1. In other words, more than 85 percent of the mass of propellants needed for space travel can definitely be supplied from lunar sources. The idea of using lunar materials in this manner is not particularly new. Arthur C. Clarke suggested that some sort of electromagnetic launcher might be used to launch propellants from the Moon in an article that appeared in 1950.[18]

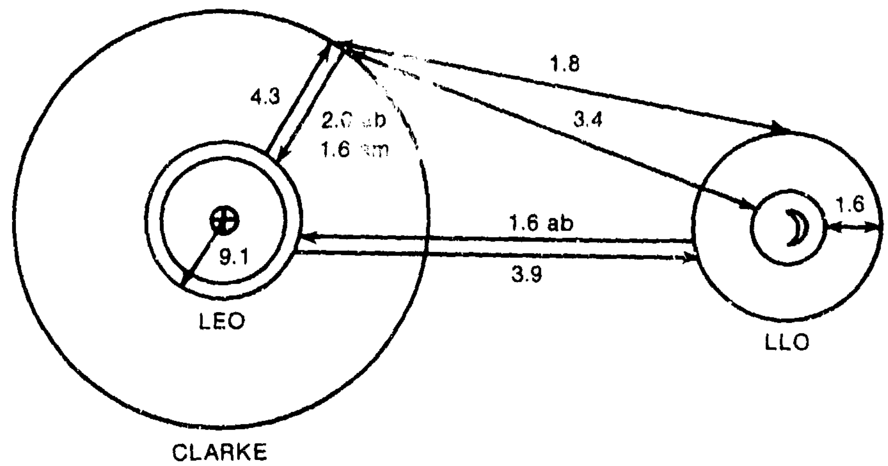
In 1976 the Boeing Aerospace Company completed a study on space transportation needs for the period of 1985 to 2000. This study examined four scenarios ranging from an extension of the present space transportation system manifest to more ambitious scenarios including placement of a commercial-scale demonstration plant in geostationary orbit for an SPS program.[19] Study results showed that *irrespective of scenario,* about 75 percent of the total mass launched from the Earth was liquid oxygen.

In a study of SPS construction from nonterrestrial materials prepared by the Convair Division of General Dynamics for NASA in 1979, Bock noted that significant reductions in Earth-launched cargo resulted from the use of lunar-derived liquid oxygen as propellant.[20] The study examined four scenarios for construction of an SPS. One scenario assumed that all construction materials would be launched from the Earth. The three remaining studies used lunar materials for construction. In addition to considering mass-drivers for launching from the Moon, cases were examined that used lunar oxygen with Earth-imported hydrogen for transport, and one scenario used powdered aluminum (from lunar sources) as well as lunar oxygen for rocket propulsion. All the nonterrestrial cases were found to be more cost-effective than the Earth-launching case, and the mass-driver scenario was found superior to the chemical propulsion cases.

The launch of lunar-processed oxygen by a mass-driver was considered by Andrews and Snow in 1981.[21] Eagle Engineering published a study in 1983 on the impact of lunar oxygen on the space transportation system.[22] This study used chemical rockets for transport from the surface of the Moon. Both studies indicated that the use of lunar-derived oxygen could have a strong beneficial impact on space activities. Both studies assumed the use of aerobraking to reduce the delta V requirements on the Earth-bound transports containing lunar liquid oxygen. Aerobraking is a technique that uses atmospheric friction to reduce the velocity of a spacecraft without expending propellant. Figure 1 details the delta V requirements for transportation in cislunar space. A comparison of the outbound and inbound (with aerobraking) cases reveals the important benefits possible with this method.

In a 1983 study published by the Jet Propulsion Laboratory, Frisbee and Jones suggested that an early profitable use of lunar oxygen would be for refueling chemical orbital transfer vehicles at geosynchronous orbit for their return to low Earth orbit.[23] The "New Routes to Space Manufacturing" study, which examined the minimum start-up size for nonterrestrial processing systems, assumed the use of lunar-derived liquid oxygen for propulsion.

Although the bulk of lunar oxygen is likely to be produced as a byproduct of chemical processing to extract metals and silicon at the space manufacturing facility, it would be useful to be able to produce oxygen on the lunar surface. This would allow chemically propelled vehicles landing men and machines on the Moon to land more payload instead of oxygen for the return flight.



LEO - LOW EARTH ORBIT 200-400 km
CLARKE - GEOSTATIONARY EARTH ORBIT (GEO) 35,900 km
LLO - LOW LUNAR ORBIT 100-200 km
ab - WITH AEROBRAKING (DRAG ONLY)
am - WITH AEROMANEUVERING (LIFT AND DRAG)

Source: William F. Carroll, ed. *Research on the Use of Space Resources, NASA* J P L Publication 83-86. (Pasadena, CA. 1983) p. 9-8.

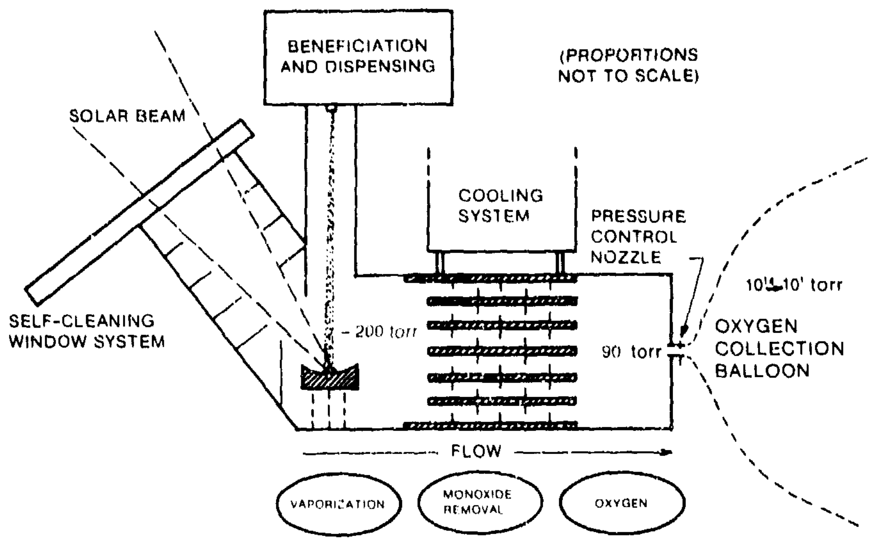
Figure 1. Cislunar Accessibility (km/sec)

Steurer and Nerad have outlined two types of vapor phase reduction for the extraction of lunar oxygen (and in some cases metals) without the use of chemical reagents or sacrificial electrodes.[24] Figure 2 depicts a vapor-separation process in which raw material oxides are heated in a solar furnace to 3,000K. The oxides are vaporized, dissociation takes place, and a substantial amount of oxygen is set free. Rapid cooling of the dissociated vapor condenses the oxides and suboxides. The free oxygen remains intact and can be collected downstream. The second process, called selective ionization, takes advantage of the fact that the metals in lunar soil are ionized between a temperature range of 4,000K to 8,000K while the oxygen remains neutral to 9,000K. The resulting charged metals can be captured at cathodes while oxygen flows into a collection system (see figure 3).

FABRICATED PRODUCTS

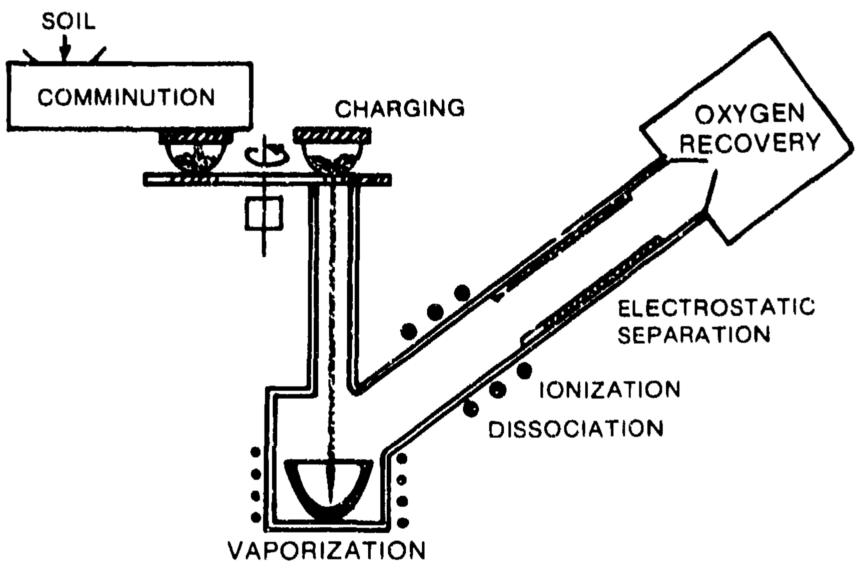
Research since 1974 has identified a number of different processes suitable for the separation of lunar soil into its constituent elements.[25] These materials can be used for the fabrication of large structures in space, including antenna farms, radio telescopes, large deep-space research vessels, and habitats for hundreds or thousands of space workers and their families.[26] Perhaps the best example of a large space system that can be fabricated from nonterrestrial materials is the one that holds the most promise as a demand driver for these materials: the solar power satellite.

The SPS concept was first presented in 1968 by Dr. Peter Glaser of Arthur D. Little Engineering Company. The basic idea is elegant and simple. A large array of photovoltaic cells would be placed into geosynchronous orbit where it would receive almost continual sunlight unfiltered by passage through the atmosphere. The resulting electricity would be imported to the surface of the Earth in the form of a microwave beam, which would be rectified at the receiving antenna and transmitted through existing power grids to consumers.



Source: *Research on the Use of Space Resources*, p. 4-2

Figure 2. Vapor Separation



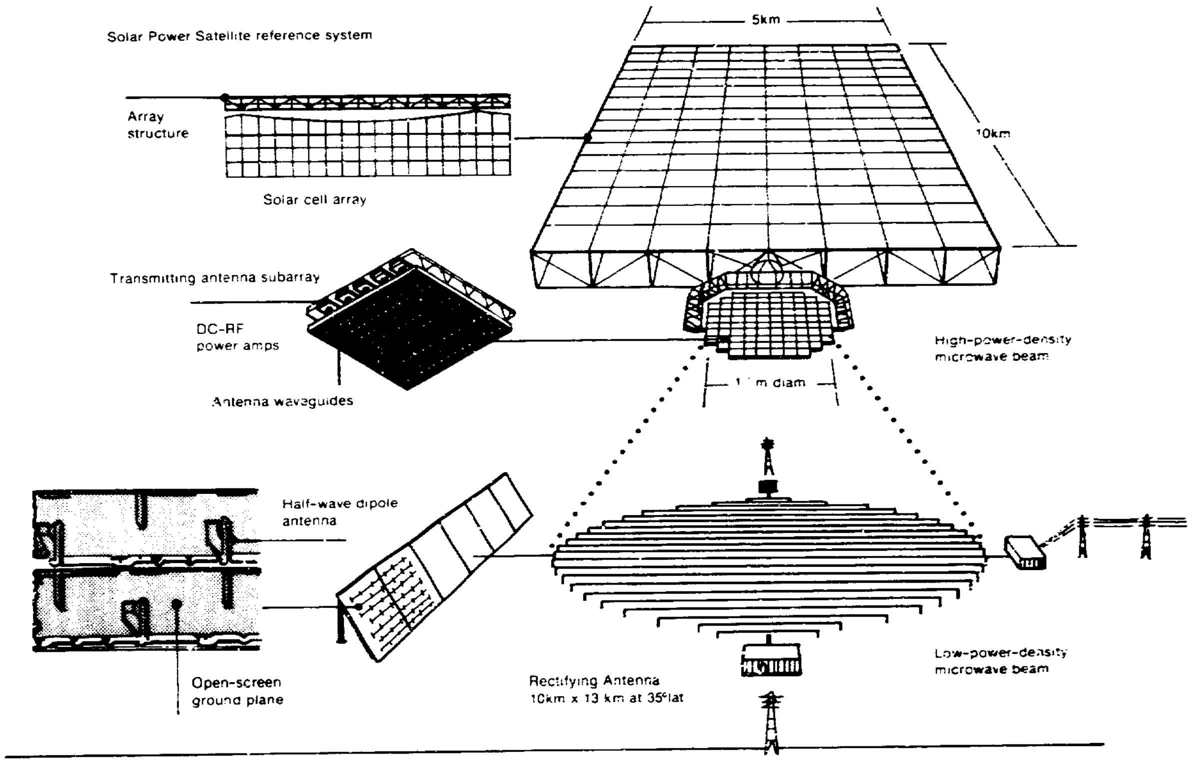
Source: *Research on the Use of Space Resources*, p. 4-5

Figure 3. Selective Ionization

Between 1976 and 1980 the Department of Energy and NASA evaluated the SPS concept.[27] The study selected a "strawman" or baseline design for the SPS for evaluation purposes. As depicted in figure 4, the reference design used solar cells as the primary energy conversion system. An alternate design for an SPS using thermal energy to expand a working fluid through a turbogenerator was eliminated from consideration as the baseline system because of the mass of radiators required for heat rejection. The selection of solar cells was motivated by the desire to minimize weight, as the SPS was assumed to be constructed from materials launched from the Earth.

In order to launch the required material from the Earth's surface, a fleet of new heavy-lift launch vehicles with payload capacities of over 400 tons would have to be developed. (Figure 5 shows the relative size of the shuttle and heavy-lift vehicles.) The Department of Energy spent more than $10 million in studies and was unable to find any technical, environmental, or social constraint that would negate the SPS concept. However, the National Research Council (NRC) reviewed the DOE study and concluded that the cost of Earth-to-Earth orbit transport would be higher than that estimated by DOE. The NRC also refused to believe that solar cells could be manufactured at the prices estimated by DOE.[28]

In short, the SPS design was too heavy to be built from materials launched from the surface of the Earth. Virtually unconsidered by the NRC, however, were two key NASA studies that examined the use of nonterrestrial resources for SPS construction. The first of these, conducted by the Convair Division of General Dynamics, concluded that more than 90 percent of the baseline SPS could be constructed from lunar materials at a substantial decrease in cost (30 percent), particularly if mass-drivers were used.[29] It is interesting to note that the Convair study came to this conclusion even without considering the effects of bootstrapping. The second study, conducted by Massachusetts Institute of Technology (under a contract to Marshall,) concluded that 96 percent of the mass of an SPS could be constructed of lunar materials.[30]



Source: See Johnson Space Center publication JSC 14898, *Solar Power Concept*

Figure 4. Baseline SPS Drawing

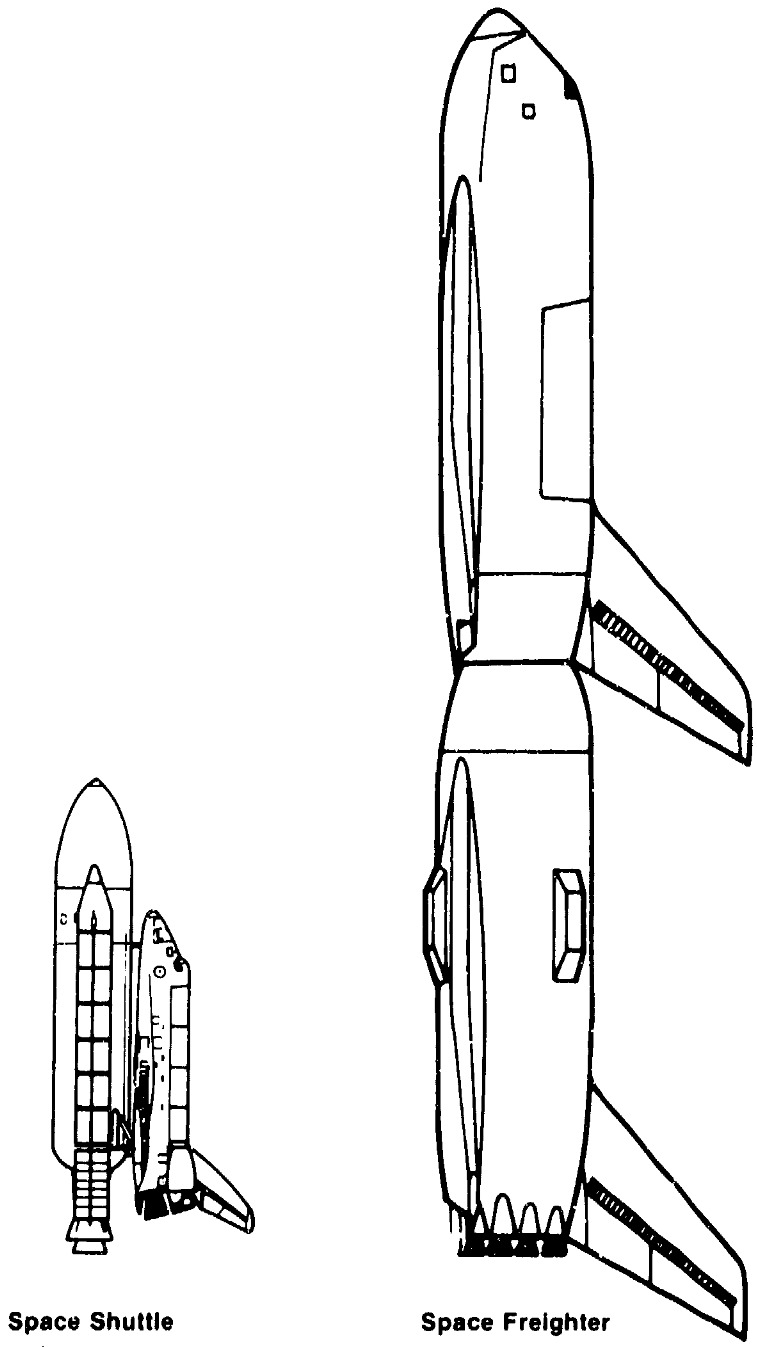


Figure 5. Space Shuttle and Space Freighter

It is also significant that these positive results were obtained even though the studies were forced to "work backward" from the baseline design in considering the use of nonterrestrial materials for construction. To obtain a more accurate assessment of the utility of constructing SPS from lunar materials, the Space Studies Institute has commissioned research to develop a design for an SPS optimized for automated construction from lunar materials. A preliminary report is expected in May 1985.[31] The use of lunar materials is expected to remove the stringent weight constraints present in the DOE research and to allow more flexibility in types of power conversion and materials, with consequent reduction in costs.

If the SPS concept is proved workable, it could create a market for between $100 billion to $400 billion worth of construction per year. Even without this particular end product, the use of nonterrestrial resources is likely to become an important future space development.

SPACE RESOURCES BEYOND THE MOON

Because the accessibility of space resources is determined by the delta V necessary to move these materials to a desired location, it makes sense to consider other materials in the solar system with delta Vs, comparable to those required to launch lunar materials. Observation and analysis shows that another major source of nonterrestrial materials for use in space exists within the solar system: the asteroids.

The use of asteroidal materials for space construction, fuel, and habitats was suggested in 1964 by Dandridge Cole and Donald Cox.[32] Many asteroids contain large amounts of high-purity nickel and iron. One class of asteroids, called carbonaceous chondrites, contains nitrogen, carbon, and water. The composition of these bodies has been determined to a high degree of certainty by examining the spectrum of reflected sunlight and by analysis of meteoric samples. The utility of water, nitrogen, and carbon for space industry and biological processes would probably justify retrieval of these resources at some point even if the delta V required was greater than that required for lunar materials (assuming that hydrogen, carbon, and nitrogen do not exist in useful quantities on the Moon).

Fortunately, asteroids exist in orbits such that total roundtrip delta V will allow retrieval.[33] These asteroids are not main-belt asteroids but are of the Apollo and Amor groups. These are asteroids whose closest approach to the sun is approximately 1 Astronomical Unit (the mean distance between the Earth and the sun). In order to achieve the minimum delta V for both outbound and inbound segments of retrieval missions, it will be necessary to use gravity assists which take advantage of the gravity fields of the Moon, Venus, and the Earth. These maneuvers can greatly reduce asteroid transfer maneuvering energy, although they add to travel time.

Retrieval missions using mass-driver reaction engines have been examined.[34] A target asteroid with an initial mass of 1 million tons could be captured. A continuous mining operation would process the body. Volatiles and other useful materials would be stored for return, while the remaining materials were fed into the mass-driver and used as reaction mass to return the asteroid to a space manufacturing facility near the Earth. If asteroids in suitable orbits are located, the cost of returning these materials may be less than for the lunar case. Spectroscopic evidence so far indicates that the Apollo-Amor asteroids, and any other with orbits well inside those of the main belt, may not be carbonaceous, and therefore may not be sources of carbon, nitrogen, and hydrogen.

Although the basic rationale for use of nonterrestrial resources is that they have a high value by virtue of their positions in space, Gaffey and McCord have suggested that asteroidal materials might eventually be imported to the surface of the Earth.[35] This might be accomplished by injecting a gas phase into processed metals to form metallic foams. The foamed metal would then be shaped into aerobodies and guided to a water landing. The foamed metal would be lighter than water, and tugs would tow the $40 million worth of pure metal contained in each aerobody to shore.

Although the long travel times to asteroids (with correspondingly high life-support requirements) and relatively infrequent mission possibilities add challenges not found in the case of lunar materials, the chemical composition of main-belt asteroids, plus the fact that high-thrust maneuvers are not required for retrieval, makes asteroids important targets for future space missions.

"WILD-CARD" SOURCES OF NONTERRESTRIAL MATERIALS

In addition to the sources of nonterrestrial materials that have been proved to exist either by sample returns or by direct observation and spectroscopy, two theoretical sources of material could prove to be exceedingly valuable to future space operations: lunar hydrogen and asteroids trapped along Earth's orbit.

Lunar Hydrogen

Since 1961, scientists have suggested that water released as outgassing during the history of the Moon might be trapped as ice in permanently shadowed areas of the lunar poles.[36] So far, however, no hard evidence for or against the existence of lunar water has been developed. The discovery of lunar water would have a large, beneficial impact on the economy of using nonterrestrial resources in space. No hydrogen would have to be transported from the Earth in order to soft-land materials on the lunar surface or to power interorbital transports. Moreover, hydrogen is a useful reducing agent for chemical processing of lunar materials. A lunar source of hydrogen would permit less energy-intensive processing of lunar materials and would reduce some of the difficulties associated with process drying for reagent recovery.

Earth-Sun Asteroids

The Earth-sun Trojan asteroids are a theoretical class of asteroids that may exist 60 degrees ahead of the Earth and 60 degrees behind the Earth along the Earth's orbit as viewed from the sun. Asteroids, known as the Trojan asteroids, have been discovered in corresponding locations along the orbit of Jupiter. These asteroids move along with Jupiter around the sun. The significance of finding as in similar locations in the Earth-sun system is that they cou recovered for a few percent of the cost of a similar mass of material.[37] Dunbar and Helin have been searching for sun Trojans from Mount Palomar. To date, their search has eliminated the possibility of bodies at these locations larger than 25-30 km in diameter. However, Staehle has pointed out that a carbonaceous chondrite only 60 *meters* in diameter could contain more than 1,000 tons of water.[38]

The potential usefulness of these "wild-card" sources of nonterrestrial materials is so great that additional Earth-based observation and space mission planning to locate or disprove the existence of these materials should be undertaken. In addition to providing very inexpensive resources for expanding space operations, the discovery of these materials would yield important scientific clues to the origin and history of the Moon and the solar system.

PRESENT STATUS OF THE NONTERRESTRIAL MATERIALS CONCEPT

NASA has requested funding for a lunar polar orbiter capable of searching for water at the poles twice, but both requests were denied. The Soviets are reported to be planning to launch a lunar polar orbiter in 1986 or 1987 and there is some indication that the French may participate in such a program.[39] It is not known if the appropriate instrumentation would be included in this mission to definitely resolve the water-ice question.

As reported earlier, Dunbar and Helin are searching for Earth-sun Trojans. Helin has been successful in locating a number of new Earth-approaching asteroids that may be suitable for future space missions.

The Space Studies Institute is currently funding a study into previously unmeasured reaction rates for certain aspects of lunar processing. The Institute's goal is to produce a bench-scale processing plant capable of producing test quantities of oxygen, silicon, and metals from simulated lunar soil.

The mass-driver has progressed from a theoretical device capable of an acceleration of 25 gravities to actual test hardware. Three working models have been completed. The first machine, constructed by O'Neill, Kolm, and graduate students at MIT, achieved 35 gravities. The second and third models, constructed and tested by the Space Studies Institute at Princeton University, advanced accelerations to 1,100 gravities. By 1985, the third model is expected to operate at full power, where it should achieve about 1,800 gravities acceleration.

THE NEXT STEPS

Nonterrestrial resources can provide a means of accelerating existing space operations such as transportation between low Earth orbit and geosynchronous orbit. Their use can enable the consideration of new programs that might otherwise be too costly to finance or complete. Key components of the launching and processing systems required to use those resources are available now or are under development.

Using these resources will enable us to make more efficient use of the space transportation system. The environmental impact of large-scale space activity can be minimized by reducing the number of launches to only those required for transport of crew and items that can be produced only on Earth.

Ultimately, space resources such as energy and virtually unlimited materials will serve as the basis for extending human habitation, industry, and agriculture to the high frontier of space. For the first time, human beings will have an opportunity to break out of the zero-sum game of limited planetary resources.

For these reasons, research on the existence, composition, retrieval, and processing of nonterrestrial materials should be accelerated. With a commitment to a permanent, manned space station and serious discussion of a return to the Moon, the time is right to begin to take advantage of the natural economies made possible by using resources already in space for our next steps in space.

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THE MILITARY USES OF SPACE

Thomas C. Brandt

If media attention is the measure, there is a growing perception that a major initiative is under way, directed toward the militarization of space. But what is meant by "militarization of space"? The term as used these days is clearly pejorative. What is often overlooked is that the military has been involved in space since the end of World War II and has had an important role in both military and civil activities in space over the last four decades. The current publicity associated with the military use of space comes from the increasingly important role, and consequent higher visibility, of satellites in enhancing the national security of the United States, its allies, and the Soviet Union.

Let us briefly examine some of the past military space-related activities. Few would argue that current space capabilities evolved rapidly because of the pioneering work of men who demonstrated revolutionary foresight. Among them were a Russian, Konstantin E. Tsiolkovsky, and an American, Dr. Robert H. Goddard. While Tsiolkovsky never built a rocket, he developed many of the theories for artificial satellites, liquid rocket engines, and manned space flight. Dr. Goddard subsequently built the world's first liquid rocket, developed operational guidance and control systems, and performed much of the early work that took theoretical ideas and turned them into practical engineering solutions.

Although the achievements of these two brilliant civilians went largely unnoticed by most of the world, Germany, in the late 1930s, recognized the military potential of what they had done. Beginning then and continuing throughout World War II, German scientists, under the leadership of Dr. Wernher von Braun, developed the A–4 rocket, which later was known as the V–2. The A–4 provided a major breakthrough in the design of space boosters.

On the evening of 3 October 1942, the first V–2 was successfully launched at Peenemuende. The project director, Major General Walter Dornberger, called his chief assistants together and presented one of the first policy statements on the use of space for military as well as civil purposes:

> The following points may be deemed of decisive significance in the history of technology: we have invaded space with our rocket and for the first time we have used space as a bridge between two points on earth; we have proved rocket propulsion practical for space travel. To land, sea and air may now be added infinite empty space as an area of future intercontinental traffic, thereby acquiring political importance. This third day of October 1942 is the first of a new era of transportation—that of space travel.
>
> So long as the war lasts, our most urgent task can only be the rapid perfection of the rocket as a weapon. The development of possibilities we cannot yet envisage will be a peacetime task. Then the first thing will be to find a safe means of landing after the journey through space.

By the close of World War II, it was clear that rocket technology had significant military potential. In the final days of that war, both the United States and the Soviet Union were eager to capture the engineers and hardware of Hitler's rocket program. Dr. von Braun, General Dornberger, and many of the key scientists and engineers who had been assembled at Peenemuende were able to get to the American lines and surrender. These rocket experts went on to work for the US Army and later became the nucleus of America's civil space program when the National Aeronautics and Space Administration (NASA) was formed in 1958.

During the late 1940s and early 1950s, the United States had a small missile and space research and development (R&D) program; however, primary emphasis was on further development of airpower and nuclear weapons. Wernher von Braun predicted that this Army team could launch a rocket that could place a satellite in orbit by late 1955. President Eisenhower opposed this endeavor because he believed that using military hardware for any space activity violated his "space for peace" policy.

On 4 October 1957, the Soviet Union stunned the world with the successful launch of the Sputnik I satellite. This remarkable event signaled the beginning of a new era, as man stretched his reach into space. Access to this new medium was to have profound effects on national security, equal in impact to the introduction of aircraft earlier in the century.

The United States quickly answered the Soviet challenge with the successful launch of Explorer 1, which was placed in orbit on 31 January 1958. Explorer 1 was launched on a Jupiter C booster that was designed, developed, and launched by the US Army.

Then, on 18 December 1958, Atlas 10–B lifted off its launch pad at Cape Canaveral, Florida, for what all but 88 people believed was a routine R&D test of our new intercontinental ballistic missile (ICBM). Several minutes into a normal ballistic trajectory, it "veered off course" and would not respond to corrective commands. A short time later a startled world discovered the Atlas' true mission from President Eisenhower. They did not read it in the newspaper: his message came from space and was in the form of a Christmas message to the world, which said: "This is the President of the United States speaking. Through the marvels of scientific advance my voice is coming to you from a satellite circling in outer space. My message is a simple one. Through this unique means, I convey to you and to all mankind America's wish for peace on earth and good will toward men everywhere."

This payload, Project SCORE (Signal Communications by Orbiting Relay Equipment), developed by the Department of Defense's Advanced Research Projects Agency, was the first military satellite launched by the United States. During the 13 days that SCORE operated, it demonstrated reliable around-the-world transmission of military teletype communications. This small start led the way for space systems that today are the backbone of civil and military communications.

The 1960s saw a continuation of the US policy of emphasizing the peaceful uses of space. President Kennedy challenged the Nation to place a man on the surface of the moon and return him safely before the end of that decade. The military was very much a part of the NASA effort in this essentially non-military venture. The Mercury and Gemini programs used converted Atlas and Titan ICBMs. The first group of astronauts were military test pilots. The military worked closely with their NASA counterparts on NASA's launch pads and control centers.

This close relationship between the US military and NASA continued with the development of the space shuttle. The decision to develop a reusable launch vehicle was based on the assumption that it would be a national system to satisfy both civil and military requirements. It was decided that NASA would develop the space transportation system and Eastern Shuttle Launch Site, while the Department of Defense (DOD) would develop a new higher-energy, upper-stage system and the Western Shuttle Launch Site. This division of responsibilities is working well. In October 1985, the West Coast Shuttle Launch facility at Vandenberg AFB is scheduled to be ready to support its first launch.

During the 1960s, the military was developing space systems that today greatly enhance our warfighting capabilities. Experimental satellites evolved into operational systems in such functional areas as communications, weather, mapping and geodesy, navigation, and surveillance. These space systems were developed because they offered the most cost-effective way of performing a national security function. In some cases they are the only way of performing that function.

It is interesting to note that the two superpowers envisage the military potential of space in sharply contrasting ways. The

United States views space as a past, present, and future sanctuary unsullied by military interactions and as a method of communicating and transporting items from one point on Earth to another. The Soviets, in contrast, view space as a fundamental strategic operating medium, one providing unparalleled opportunities and fulcrums for applying national power to achieve permanent advantage. They see space as geopolitical high ground.

The Soviet space program is a dynamic and expanding effort, resulting in approximately 100 launches per year. Some 85 percent of these launches are exclusively military or joint military and civilian missions. The annual Soviet payload weight placed in orbit reaches an even more impressive total—660,000 pounds—10 times the payload of the United States. This level of effort reflects the importance the Soviets place on their space program; it also reflects a technological weakness that they overcome by a number of launches of less complex systems. Soviet military and military-related space programs include meteorological, communications, navigational, reconnaissance, surveillance, targeting, and extended manned missions. Furthermore, with the development and employment of an orbital antisatellite (ASAT) weapon more than a decade ago, the Soviet Union clearly signaled its recognition of space as an arena for weapons.

The Soviets have a formidable inventory of space launch vehicles. Of greatest interest is their new generation of space boosters, including a Titan-class expendable booster and a Saturn-V–class heavy-lift launch system that will probably be used to launch the Soviet version of the space shuttle as well as other heavy payloads.

The goal of these new heavy-lift launch systems will probably be to launch and support a large manned space station by about 1990. Such a space station could weigh more than 200,000 pounds and could support a large crew for extended periods without replenishment. This would be consistent with the increasingly complex nature of current Soviet manned space missions, which constitute the single most extensive element of the Soviet space program.

Since 1971, the Soviets have placed seven space stations in orbit. In 1977, the Soviets launched Salyut 6, which was equipped with a second docking collar to accommodate the unmanned Progress cargo vehicle and the Soyuz cosmonaut ferry. These features provide the Soviets with the capability to resupply and exchange personnel on their Salyut space stations. On three occasions the Soviets have conducted manned missions lasting as long as 6 months. With the completion of the 237-day mission on board Salyut 7 this year, the Soviets set a new space endurance record.

Although the Soviets did not take advantage of geostationary communication satellites as early as Western nations did, recent filings for communication satellite placement and frequencies indicate their intentions to do so. The Soviets have also embarked on an ambitious expansion of their communication satellite program that will add measurably to their global command, control, and communications capability. Over the next 10 years, the Soviets will develop and deploy an even more advanced series of communication satellites, some of which might relay transmissions from manned orbital command and control platforms to ground, sea, and air elements.

The Soviet military space program also reflects an ever-increasing use of space for worldwide surveillance and attack warning. They have a number of US and allied military forces under surveillance by satellites that include an intercontinental ballistic missile launch detection system and an ocean surveillance system. Soviet efforts in the surveillance field are expected to lead to a multisatellite detection, surveillance, and attack warning system against ballistic missiles, and possibly bombers as well.

They have also steadily increased their space photographic and electronic reconnaissance effort since the early 1960s. Each year more than 50 of these satellites are launched to provide continuous support to military forces. The several different satellite systems in use provide target location, tar ' identification and characterization, order-of-battle, force mor. ing, crisis monitoring, situation assessment, geodetic information for improving accuracy of ICBM targeting, and mapping for military forces.

The Soviets have clearly grasped the military advantages that will accrue to the nation that is able to gain and maintain control over space. They are the only nation in the world with a dedicated ASAT weapon, designed to destroy low-orbiting satellites. They are conducting a very large, directed energy research program which we believe may result in the development and deployment of a space-based laser system. We estimate that the Soviets could launch the first prototype of a space-based laser ASAT in the late 1980s. An operational system capable of attacking other satellites within the range of a few thousand kilometers might be possible in the 1990s.

The Soviets also maintain the world's only operational antiballistic missile (ABM) system around Moscow. They have an improving potential for large-scale deployment of modernized ABM defenses well beyond the 100–launcher ABM Treaty limitation. Widespread ABM deployment to protect important target areas in the Soviet Union could be accomplished in the next 10 years. They have developed a rapid deployable ABM system that could be operational in months rather than years. The new, large phased-array radars under construction in the Soviet Union—along with the early-warning radar HEN HOUSE, other radars (DOG HOUSE, CAT HOUSE), and possibly the Pushkino radars—appear to be designed to provide support for such a widespread ABM defense system. The Soviets seem to have placed themselves in a position to field a nationwide ABM system rapidly should they decide to do so.

In contrast, the US space systems of today are used predominately to provide communications, early warning, navigation, and weather support to our land, sea, and air forces. Currently, more than two-thirds of our long-distance military communications are sent via satellites. Military space communications systems are designed to ensure dependable and timely command, control, and communications functions on a global basis. The two systems carrying most of the workload are the Fleet Satellite Communications (FLTSATCOM) and the Defense Satellite Communications Systems (DSCS). By the early 1990s, the MILSTAR communications satellite will become operational, and improvements will be made to DSCS. As a result, the ability of the National Command Authority to communicate with strategic and tactical forces under all wartime conditions will be significantly improved.

Early warning and surveillance satellites monitor ballistic missile launches and detect nuclear detonations on a global basis. Early warning satellites provide the first indication that the United States or our allies are under ballistic missile attack. A reliable, enduring, and survivable early warning system is our first line of defense and a vital element of deterrence. Consequently, we are increasing our efforts to enhance the survivability of these systems by improving both the ground and space elements. Nuclear detonation sensors not only monitor our potential adversary's compliance with test ban agreements, but in addition, provide our force planners with vital information on surviving friendly resources and enemy target destruction in time of war.

We also use space systems to provide our forces with precise navigation data. Today, we are in the process of deploying the NAVSTAR global positioning satellite (GPS) system, which will provide users in all services with three-dimensional position and timing information on a round-the-clock, global basis under all weather and visibility conditions. GPS precision navigational data will increase the probability of damage to targets and enhance our flexibility under a strained combat logistics environment by enabling the delivery of iron bombs with accuracy approaching that of smart weapons. GPS will allow low-level ingress/egress for flexible routing, as well as totally passive operations for increased survivability.

GPS will also provide accurate navigational data to the civil community. This is a prime example of the overlap of benefits that often occurs between the civil and military uses of space.

And it is a significant reminder that all US space systems, whether military or civil, contribute to our national interests by supporting policies that are important to our society.

The Defense Meteorological Support Program (DMSP) provides accurate and timely weather data, which is vital to successful military operations. The DMSP is DOD's single most important source of weather data. Efforts are under way to laser-harden the DMSP spacecraft and sensors as well as to improve the hardness of its ground operations center.

Because of the importance of space systems to our nation's defense, we must protect them from enemy threats while denying adversaries the use of their space systems during hostilities. It is clear that the potential for space to become a hostile environment for both the United States and Soviet Union is increasing for two reasons. Space systems are becoming increasingly important in support of military forces, and second, the technology that makes space conflict possible is maturing.

To deter threats to our space systems and, within limits imposed by international law, to counter certain satellites that provide direct targeting support for hostile military forces, we are continuing to develop an ASAT system. Unlike the existing and often-tested Soviet system, which is a ground-launched co-orbital intercept satellite, the US ASAT is a miniature vehicle on a two-stage short-range attack missile SRAM/ALTAIR booster carried aloft and launched from a specially modified F–15 aircraft. This ASAT system will correct the basic imbalance between US and Soviet capabilities.

DOD is also involved with launch and recover, orbital transfer, and on-orbit control of space assets. During the 1980s, space scientists are making major improvements to enhance our capabilities to launch and control military satellites. By the end of the decade, most DOD satellites will have completed the transition from expendable launch vehicles to the space shuttle. However, DOD is concerned about total reliance on a single launch system. In view of the importance of space systems to our national security, DOD will develop and procure 10 new expendable launch vehicles through the early 1990s to complement the shuttle. To be able to place even heavier payloads in high-altitude orbits, we are working with NASA to develop a more capable upper stage, based on the Centaur cryogenic stage used since the early 1960s, which will be available for shuttle use by 1986.

Once satellites are on orbit, DOD operates a worldwide ground station network under the control of the USAF Satellite Control Facility in Sunnyvale, California. To enhance the command and control of space assets during the 1980s, the Consolidated Space Operations Center (CSOC) is being built in Colorado. Once it becomes operational, CSOC will share the Satellite Control Facilities workload besides providing a centralized, secure, and more survivable facility for planning and conducting DOD space missions.

Looking ahead 10 years or so can be very stimulating. Speculating on the future can also be risky. Indeed, it is difficult to predict what will happen in the next hour. I am reminded of General John Sedgwick's last words just before he was killed at the Battle of Spotsylvania Courthouse when he said, "Don't worry, men, they couldn't hit a elephant at this dis. . . ." Aren't we, today, often just as shortsighted as General Sedgwick? Space-based systems will expand beyond those of today. The Soviets have already experimented with weapons in space with their fractional and multiple orbital bombardment systems, which were tested two decades ago.

In March 1983, President Reagan offered the hope of making the world safe from the threat of nuclear ballistic missiles. Although the President did not specifically state that his ABM defense system would be space-based, many of the potential solutions rely heavily on space-based defensive weapons. Both *Time* and *Newsweek* quickly had cover stories that referred to the President's initiative as "Star Wars." I have little doubt that any comprehensive ABM system will have to have some type of space-based support platforms to attack incoming targets. Regardless of the solution, years of research will be required before a decision can be made concerning the feasibility of a comprehensive ballistic missile defense. As we pursue ballistic missile defense research, there will inevitably be many ideas and advocates for delivery of weapons from space.

I am optimistic that the use of space for military purposes will continue to enhance the security of the United States and our allies. History has often been changed by the nation that first grasped the advantages offered by developing the military potential of the newest medium. The Soviets have certainly recognized the value of space systems in support of military operations. The United States cannot and will not ignore the value of the military use of space and allow the Soviet Union to dominate the "ultimate high ground."

We must have the foresight to recognize emerging technologies and their potential military applications and be prepared to seize these opportunities when it is in our national interest to do so. Military requirements and the technology to satisfy those requirements are constantly changing and we must be perceptive enough to recognize those changes. Although he was speaking about the military potential of airpower, Guilio Douhet summed it up best when he said, "Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after changes occur."

C^3I ASPECTS OF SPACE TECHNOLOGY

Donald C. Latham

I shall look at two distinct but related areas. First, we should consider the use of satellite technology within the framework of command and control; by this I mean the command and control of our current force structure and weapon systems, all of which are terrestrially based. Satellites play an important role in C^3I, and they will continue to do so.

The second perspective is that of command and control of any weapon systems that might be associated with the Strategic Defense Initiative (SDI). Under the current breakout of SDI tasks this mission is being referred to as "battle management," but regardless of the title, it represents the almost classical command and control process being applied to a potential new class of weapon systems.

COMMUNICATIONS SATELLITES

Getting back to our current and proposed C^3I systems, the most obvious use of satellites is, of course, communications in support of the total command and control function and for military communications in general. Our current communications satellite architectural approach evolved from a number of independent approaches developed in the 1970s. The GAPSAT, FLTSAT, and LEASAT satellite systems were designed to provide ultra-high frequency (UHF) services, mainly for our forces afloat, but also for other mobile and tactical users. The architecture of the Defense Satellite Communications System (DSCS) evolved from the DSCS II to the DSCS III in support of the defense communications system and other wide-band users. At the same time, the Air Force Satellite Communications System (AFSATCOM) was developed and implemented with transponders on FLTSAT and SDS satellites. To improve survivability, the tactical satellite community proposed a General Purpose Satellite Communications System (GPSCS), and the Air Force proposed a Strategic Satellite System (SSS).

These proposals were combined in a joint study in the late 1970s to provide a single program to satisfy the survivable narrow-band tactical satellite communications needs of all services. This merging was assisted by the Congress, which deleted the funds for the SSS program on three successive occasions. The combined architecture study resulted in the design of what has come to be known as the MILSTAR Satellite System which will operate in the millimeter-wave frequency range called extremely high frequency (EHF). MILSTAR is a single satellite system design to serve the survivable narrow-band communication needs of all the services and agencies in the Department of Defense into the next century.

So much for the past. Our current satellite architecture consists of the DSCS system for wide-band channels, the FLTSAT system and the first two LEASAT satellites at ultra-high frequency (UHF) for the general purpose forces, and the UHF AFSATCOM system for the nuclear force. These systems are augmented by a significant quantity of leased commercial communications satellites. The total MILSATCOM system and the features of each element can be summarized as follows:

The Defense Satellite Communications System supports a variety of intelligence, ground mobile forces, and tactical warning/attack assessment users that we usually lump together under the category of command/support. The system operates in the 7/8-GHz super-high-frequency (SHF) bands and provides some survivability for selected users. Significant features include high data rates, fixed and mobile terminals, and the ability to support some jam-resistant networks.

Our command/support users also use commercial satellite capacity for similar purposes. These are normally in the 4- to 6-GHz bands. High capacity can be provided at somewhat lower costs, but special provisions for survivability or jamming protection are not currently available, and I do not expect such expensive features in the future.

The AFSATCOM system supports our nuclear-capable forces, operates in the 200- to 400-MHz band, and possesses some degree of survivability and jam-resistance.

The FLTSAT/LEASAT system also operates in the 200- to 400-MHz band for tactical, manpack, and fleet units. This UHF ultra high frequency system supports a large number of inexpensive and mobile terminals employed by a variety of forces.

To recap our current MILSATCOM capability by on-orbit assets:

- In SHF we have six DSCS II satellites, of which four are operational and three are considered on-orbit spares, and one DSCS III satellite , which is operational. Through agreements with our allies, we could have access to one operational NATO III satellite and two spares if we encountered unanticipated problems with the DSCS system.

- For our nuclear-capable forces, we have AFSATCOM channels available on SDS, FLTSAT, and other hosts.

- In the UHF band for our conventional forces, four FLTSATS and one LEASAT are operational (the second was launched in November) and three GAPSATS (i.e., our title for MARISAT leased capacity) are partially operational.

- In addition, we have leased approximately 100 MHz of total satellite bandwidth in commercial satellite systems such as WESTAR, SATCOM, COMSTAR, ANIK, and others. This bandwidth represented approximately 1,100 individual circuits in 1982, of which the greatest single user was the Defense Communications Agency. Circuit numbers for 1983 are not final yet, but the total is likely to be higher.

So far we have covered both the historical and current capabilities of our SATCOM programs. Next we should touch on the programs currently in design or production. The MILSTAR system is currently planned to provide service for critical strategic and tactical users by 1990. We plan to deploy these satellites in both high- and low-inclination orbits. MILSTAR will operate in the extremely high frequency (EHF) band at 20 to 44 GHz, where the ability to generate narrow or spot beams to serve distinct regions on the surface of the Earth is within the scope of current technology. However, because we must also develop technique and procedures to operate in this new frequency band, we intend to place an EHF package on (FEP) our last two replacement FLTSATs, numbers seven and eight, to serve as a test package for developing militarized EHF terminals.

The more sophisticated MILSTAR EHF satellites will follow FEP by several years. The MILSTAR configuration will feature such capabilities as "crosslinks," a UHF capability for backward compatibility to existing terminals and multiple-spot beams. High anti-jam capability is available because of extremely wide bandwidths available at EHF in which sophisticated, jam-resistant waveforms can be employed. MILSTAR will provide data and voice circuits to our tactical and strategic users only at rates of between 75bps and 2.4 Kbps. Every effort will be made to ensure that the system provides both survivability and endurance by use of onboard processing, cross banding, crosslinks, common modulation, interoperability, hardening, and autonomy. MILSTAR terminals are being designed for ground mobile, aircraft, shipboard, submarine, and fixed applications.

No other new satellite communications systems are in this phase of development. Additional FLTSATS, LEASATS, and DSCS III satellites will, of course, continue to come on line based upon our current programs until the early 1990s. Commercial satellite capacity will also be available for lease in those instances where defense requirements appear to coincide with commercially attractive circuits and features.

Despite this satellite capacity, shortfalls continue to be a problem. Requirements for defense satellite services are increasing while the available number of channels is either constant or decreasing and the number of deployed terminals is also rising at a significant rate. We intend to attempt to meet these additional requirements within the bounds of technology and affordability.

SUBARCHITECTURES

Up to this point we have been working with an architecture that evolved from various semi-independent approaches; for the most part, this architecture was based on the need to meet significantly diverse requirements for service. Starting in the early 1990s, we plan to turn this architecture from one driven by existing programs and users into a cohesive set of achievable subarchitectures. The need for this is apparent. We simply cannot afford to expend resources in providing expensive survivability and jam-resistance for military missions with small benefits. Even more to the point, our critical command and control functions cannot be entrusted to highly vulnerable systems, whether satellite provided or otherwise.

Although the common perception is of a single, overall architecture, our experience in the MILSATCOM area has shown that the problem is just too difficult to handle in that way. Instead, we published a MILSATCOM architecture framework in May 1984, a MILSATCOM architecture plan in September, and an overall architecture in November. This framework allows us to consider four subarchitectures for addressing what we currently perceive to be the areas of greatest concern and allows expansion into other subarchitectural areas when and if needed. Our subarchitectures will deal with post-DSCS III, MILSTAR Block III, post-FLTSAT/LEASAT and commercial SATCOM. We have identified these key areas for architectural supporting studies:

AFSATCOM transition
Multimission satellites
User requirement categorization
Funding
Integrated threat concepts
Impact of SDI
Frequency/orbit utilization.

Of the subarchitectures, let us first consider the post-DSCS II or SHF issue. What are the driving factors here? First, our threat projection shows that the technology available for construction of ground-based jammers is becoming more widely available and that we can expect a steadily increasing jamming environment throughout the 1980s and 1990s. In such an environment, the DSCS anti-jam capacity will be considerably reduced at the same time that our requirements for wide-bandwidth, high data rate, anti-jam circuitry are increasing. The crossover point is expected during the 1990s. We also expect to continue fielding SHF SATCOM terminals to reach a projected total of some 800 by 1990, with even more possible after that. And, of course, the statistical probability of availability for the current constellation of satellites will also start falling off in the early 1990s.

In the face of other expenditures and the advent of technological opportunities in the EHF band, we have determined that only evolutionary improvements to DSCS III will be allowed. We envisage no new SHF SATCOM program starts, because basically all the current driving factors are also evolutionary. What options does this leave? Obviously the choice to replenish with additional DSCS III "as is" might be attractive. Other alternatives to be considered would include DSCS III with SHF enhancements, with or without an additional EHF package, or perhaps with a complementary EHF package on other hosts.

To examine these options, let us consider some potential DSCS III improvements. Capacity could be increased by adding more satellites on-orbit, either shared or dedicated. Additional jam-resistance could be traded off against EHF options. Similarly, reliability might be increased through more component redundancy or solid-state amplifiers. Nuclear mitigation and mobile satellite control ground stations could increase survivability.

On the basis of these considerations, we have proposed a strategy for achieving survivable and enduring wide-band service, which began with preliminary studies and requirements definition tasks in fiscal 1984 and which will lead to industry briefs in early 1985. Additional trade-off studies, full-scale development, and subsequent satellite construction could lead to additional wide-band capabilities in the early 1990s. These capabilities would be responsible to our current architectural study and would assure us of continued capabilities for existing and planned terminals and users. However, we have not decided on the exact approach. We expect to take full advantage of the industrial base in satellite technology to advise us on alternative solutions and to keep us from making premature judgments on the technology and techniques most suitable for the mid-1990s.

SYSTEMS AND NETWORKS OF THE WIDE-BAND ARCHITECTURE

We make considerable use of commercial satellite circuits, and, for a multitude of reasons not related directly to our MILSATCOM community preferences or even to the desire of our end users, we will probably be using even more of them in the future. One reason is the transition of the traditional Department of Defense (DOD) common user telecommunication systems, the automatic voice and digital networks (Autovon and Autodin), into the defense-switched network (DSN) and the defense digital network (DDN), and eventually into a worldwide digital system architecture (WWDSA). These changes, together with the freedom to implement many new types of network alternatives because of the divestiture of AT&T will eventually lead us away from the typical hierarchical switched networks that usually favor terrestrial transmission systems.

These more advanced system architectures usually prefer a multinode, fully connected topology, where SATCOM becomes both more economical and operationally attractive for long distance connectivity. In other words, if each DOD post, camp, or station is equipped with a capable communications center and suitable switching equipment, it may be preferable both from cost and grade-of-service aspects to use more SATCOM circuits for the communications essential to carry out administrative, training, logistics, and support functions.

Of course, much depends on the degree of competition from common carriers using more modern terrestrial systems, and on the availability and cost of fiber-optic networks. However, we must assume that commercial satellites will carry an ever-increasing quantity of internal DOD telecommunication traffic and will be increasingly used by contractors heavily involved in providing our industrial base.

Thus we have drafted a policy statement on the application of communications security to space systems. It states that classified and government/contractor national security related information transmitted over satellite circuits shall be protected. Government and contractor use of US civil and commercial satellites launched 5 years after the effective date of the policy will be limited to those using approved techniques for protection of essential elements of telemetry, tracking, and control, as well as mission data.

We must consider several initiatives in our commercial satellite subarchitecture. In each case we must be prepared to consider survivability of the satellites and their ground control network and the existence of plans and procedures to control access to the satellite systems during emergencies.

Although DOD and its supporting industrial base do not represent a majority of users, together we use one of the largest single blocks of service. Consequently, we have a vested interest in ensuring compatibility and interoperability of communications channels, both among service providers and between our own systems and the commercial world. We also would be pleased to see the commercial systems consider such features as encryption of command links, interoperability telemetry and control circuits, and physical security of key ground facilities. Each of these initiatives is being addressed in the commercial satellite subarchitecture studies now under way in the National Communications Systems office. Several of these initiatives could be achieved by simple changes in protocols and operational procedures, but we also need to evaluate costs and potential benefits for more complex initiatives that might involve substantial resources.

After this explanation of our wide-band architectural driving factors, there probably are not many surprises for the post-FLTSAT/LEASAT subarchitecture, Unfortunately we have already run out of satellite bandwidth needed to support the tactical nets that have firm requirements to operate in the UHF band. The reasons are obvious: the existing designs provide 25 KHz channels with no easy way for users to share an individual channel, and, perhaps more important, there is a surplus of UHF transceivers available in the $20,000 range that allow access to a satellite channel.

Some members of the higher level operational community view UHF satellite service as the military equivalent of a worldwide cellular radio, but that is just not the case at present. But we do need to reduce the cost of UHF satellites and increase the efficiency of channel utilization so that our critical users can have the connectivity they desire. Efficiency can be improved by lowering data rates. Secure voice digitized at 2.4 Kbps in lieu of 16 Kbps is now feasible and becoming more widely available. This, together with the introduction of demand-assigned multiple access (DAMA) techniques could offer some increase in channel efficiencies. The drawbacks are, of course, additional complexity and cost in the terminal equipment. Perhaps these factors alone will slow down the rather explosive growth of user terminal acquisition.

We have also tentatively decided to remove the processed channels from FLTSAT and not to include an AFSATCOM package on any new UHF satellites. Our goal would be to have a follow-on to FLATSAT/LEASAT with a capacity of 50 to 75 channels optimized for either the shuttle or expendable launch vehicle and operable within existing frequency plans and orbit slots.

We also plan to maintain the present size and weight of the satellites. Low-risk, proven technology will be a driver. Because we will be changing over the strategic and nuclear-critical command and control users to MILSTAR by the mid-1990s, we can relax the nuclear survivability requirements on the future UHF satellite system. This action could allow us to make the UHF capability more affordable by simply leasing a "commercial" satellite system developed by industry. Of course, we are keeping open all other acquisition options to ensure adequate competition and flexibility. The Navy is the Department's executive agent for UHF SATCOM and has already briefed industry on our plans.

To achieve our first launch in 1991 we have an ambitious schedule which involves awarding contracts for spacecraft production by 1986. Prior to an award, we must still complete both our architectural guidelines and the normal pre-contract-award activities. The cost reduction expected in UHF SATCOM will be possible, at least in part, because some of the existing circuits and requirements, such as nuclear survivability, are being met by programs in support of other subarchitectures, again pointing out the need for an overall architectural framework.

Even though we have all but written off achieving any reasonable degree of jam-resistance in our UHF SATCOM system, work is still being carried out in the commercial area on the erection of rather large, multiple-beam, space reflector systems that could offer relatively narrow beam widths at these lower frequencies. For example, a 150-meter wrap-rib reflector may be proposed for commercial use in the 800-MHz mobile radio band. Our architecture should not shut out advantages gained by the application of this and other new techniques.

The last of our core system subarchitectures will be the MILSTAR Block III, which is not sufficiently advanced in concept to warrant discussion here.

In summary, our strategy is to provide a wide-band service through the DSCS and its follow-on system; continued use of commercial SATCOM; a narrow-band, extremely survivable strategic and tactical service via MILSTAR; and continued UHF service for the foreseeable future. Our satellite communications architecture itself, however, is dependent on and influenced by a number of other activities. First, as mentioned earlier, we must contend and harmonize with other architectures. Not only are common user communications undergoing both technological and business area changes, but within DOD we have become more involved in architectural approaches to such items as intelligence communications architecture (INCA) and the need to treat reconstitution of forces from an architectural perspective. Finally, coordination with our allies, especially NATO, leads us to other architectural approaches and trade-offs.

RADIO NAVIGATION

Our new satellite-based global positioning system (GPS) is being designed to provide global, all-weather, 24-hour, accurate, three-dimensional position and velocity information to suitably equipped users. When the operational space segment is completed in 1988, a constellation of 18 satellites will be placed in nominal 10,900-nautical mile orbits with a period of 12 sidereal hours. Six planes inclined at 55 degrees will contain three satellites each so that any point on or near the Earth's surface will be within line-of-sight of at least four satellites at all times. A navigation accuracy of 100 meters for general systems users and a higher accuracy—16 meters—for US and NATO military users is planned.

The satellites are hardened against nuclear effects and it would require a "one on one" attack to destroy the constellation. On-orbit spares also will be employed to ensure high service availability. GPS is the host vehicle for the nuclear detection system (NDS) which has been designed to help us in global detection of nuclear detonations.

Although the satellite and ground control segments of GPS certainly represented challenging technological issues, at present we are emphasizing the integration of satellite receivers into military platforms. We have the use of six research and development (R&D) satellites, three of which were placed into orbit in the past 2 years, to allow for the development of this user equipment. Again, the introduction of a new capability into a variety of aircraft, missiles, spacecraft, ships, and land vehicles is a complex undertaking. In this case, the new service supplements and will eventually replace some of the existing systems such as long-range navigation (LORAN-C), OMEGA, inertial navigation systems (INS), ultra-high-frequency tactical air navigation (TACAN), and TRANSIT satellites. This requirement alone calls for carefully designed, backward-compatibility features, transition plans, and provisions for growth via preplanned product improvements (P^3I). In addition, because each of these existing services lacked many of the features and performance of GPS, total changes in operational concepts, mission planning, and even tactics may be necessary. Because we are deeply involved in working with our allies in GPS, we are also taking extreme care to ensure that all lessons learned from US user equipment testing is also applied to the NATO configurations.

Since 1980 DOD and the Department of Transportation (DOT) have published a jointly prepared federal radio navigation plan biennially. The 1984 version is nearing publication. This version will contain a DOD/DOT policy for the future radio navigation systems mix signed by DOD Secretary Casper Weinberger and DOT Secretary Elizabeth Dole. This policy statement sets forth the phase-in/phase-out dates for federally funded radio navigation systems for the remainder of this century and into the next. In summary, this statement indicates that, starting in 1988, the GPS will be phased in. The GPS will then be the radio navigation system used to phase out TRANSIT and land-based TACAN and military use of LORAN-C, OMEGA, and very high frequency omni-directional range distance-measuring equipment (VOR/DME). If GPS meets several conditions, it will also be used to phase out the civil LORAN and OMEGA systems.

Another important policy was changed this fall. In 1981 the Armed Services and Appropriations committees of the Congress directed DOD to establish a plan to collect user charges for non-DOD use of GPS. After more than 2 years of study and some design work, DOD submitted a report to Congress stating that because of implementation, safety, and precedent problems user charges were both impractical and undesirable, recommending that user charges for the standard positioning service be rescinded. The Armed Services committee rescinded the user charges this September. As a result, GPS will broadcast the standard positioning service (GPS) signal with an accuracy of 100 meters in the clear, for use by those equipped with a proper receiver, without charge.

There are at least three civil applications in which the 100-meter accuracy is insufficient. These applications are offshore oil exploration, harbor/harbor approach navigation, and surveying. Three methods to improve accuracy are being investigated to meet these requirements.

The first method is to allow limited civil use of the GPS precise positioning service. The White House has approved a policy to allow this access in the "national interest." We are in the process of establishing a method for implementing this policy. Our initial plan consists of four major features:

- An interagency group would be established to review all applications (foreign or domestic). Approval or disapproval would be based on national interest and whether other accuracy enhancements could be used instead of the precise positioning service to meet the requirement.
- A third party (either government or contractor) would be established to provide the precise positioning service. This group would have the crypto and the user sets.
- The approved applicant would have the third party provide the service at any site where very accurate position data was needed.
- The service would be cost reimbursable.

The second method for increasing accuracy, especially for relative navigation, would be to develop a differential GPS mode that could be used for harbor and harbor approach applications. Known GPS errors from a fixed location would be broadcast to surrounding units for their use in calculating more exact locations. Several standards organizations are considering maritime and aeronautical applications of a differential system.

The third method for applications such as surveying would have the Defense Mapping Agency release ephemerides in non-real time (that is, after a delay of several days). This would allow the precision necessary for typical surveying calculations while still reserving the precise real-time mode for its intended applications. Other, more imaginative technical solutions will probably appear once GPS becomes fully operational.

Before leaving the topic of satellite systems used to support C^3I functions, we should also be aware that the national space policy states that the space transportation system (STS) is the primary US government space launch vehicle. Our policy further states that unique national security requirements may dictate development of special purpose launch capabilities in addition to the shuttle.

On 7 February 1984, the Secretary of Defense announced the DOD space launch strategy directing the Air Force to procure expendable launch vehicles (ELVs) to complement the shuttle and be able to launch selected spacecraft on these vehicles no later than FY 1988, at which time the last of our current stockpile of ELVs will have been expended. These vehicles must provide a launch capability essentially equal to the original STS weight and volume specifications (that is, 10,000 pounds to geosynchronous orbit).

The rationale for this decision was that our previous space launch planning specified that DOD would rely solely on four unique, manned orbiters for the access to space needed to support all national security space systems. Our studies and other independent evaluations concluded that such a capability would not represent an assured, flexible, and responsive access to space for defense purposes. We are fully committed to the STS, but total reliance on it for sole access to space represented an unacceptable national security risk. A complementary system is necessary to provide high confidence that access to space will be maintained, particularly because the shuttle would be the only launch vehicle open for all US space users.

Any solution to this problem must be both affordable and effective. It must meet the highest performance standards and have a low technical risk with reasonable schedule availability. Unmanned, expendable launch vehicles meet these criteria and satisfy our operational needs for a launch system that complements the STS and extends our ability to conduct launch operations further into the spectrum of conflict. These systems could provide unique and assured launch capabilities in peace and in crises and conflicts short of general nuclear war.

The Air Force requested proposals for this complementary expendable launch vehicle in April 1984. Because of changes requested by other agencies and the Congress, the request was further amended. Two contractors plus NASA have responded to the request for proposals.

After selecting the better of two contractors' proposals by mid-September the Air Force will then compare the chosen scheme with NASA's proposal and award the contract to the overall winner in February 1985.

In addition, Congress has requested that the DOD, in conjunction with NASA and the Office of Management and Budget (OMB), review ELV needs and requirements for 1988 and into the 1990s. Included in this study will be an assessment of the applicability of shuttle-derived technology to both near-term and heavy-lift configurations, and the viability and reliability of the space shuttle as a sole means of access to space through the late 1980s. This study is expected to be transmitted to the Congress in January 1985.

With regard to smaller class payloads, such as GPS, (DMSP) and certain support missions, the Defense Resource Board directed the Air Force to investigate the use of Titan IIs to perform space missions. On the basis of this investigation, the Air Force recommended that Titan IIs be converted for space use. Current plans are to issue a request in February 1985 for a proposal that addresses the conversion of 12 Titans and the necessary pad modifications at Vandenberg Air Force Base. The schedule calls for an authority to proceed in FY 1986 with a first launch in FY 1990. In addition, The National Oceanic and Atmospheric Administration (NOAA) has expressed possible interest in using converted Titan IIs for their polar-orbiting satellites.

The Strategic Defense Initiative (SDI) will eventually have a major impact on the C^3I community. The current SDI efforts consist of research and technology pursuits. Development decisions are not expected until the early 1990s. Programmatically, five large program elements are being supported by C^3I, but our primary emphasis is on two of these. Surveillance, acquisition, tracking, and kill assessment (SATKA) is of real concern. Of the $1.4 billion included in the FY 1985 budget request for SDI-related R&D, about $570 million is for projects related to SATKA. The other technical area that has been included in the systems program element, battle management/C^3, will expend about $60 million in FY 1985. The three remaining areas, namely, directed-energy weapons, kinetic-energy weapons, and survivability, lethality, and subsystems also have some impact on C^3I functions.

Our current analysis is centered on a multiple-layered defense against intercontinental ballistic missiles (ICBM) and the possible use of the applicable layers of the system against submarine-launched and intermediate-range ballistic missiles (SLBM and IRBM). Typically, multiple-layered defenses consider target availability in the boost, postboost or bus deployment, midcourse, and terminal phases of the trajectory. Engagement during each phase presents widely differing requirements to our C^3I capabilities. However, five key technological programs have been ranked for initial C^3I planning purposes.

First, under the category of fault tolerant processing we will concentrate on defining architectures, developing critical technologies, and initiating fabrication and test efforts to space-qualify the systems and components needed to carry out these functions.

Failure free software tasks will be subject to architectural definition and analyses. Tools and simulators to produce and check this category of software will be emphasized. Knowledge-based or artificial intelligence developments will be undertaken.

The matter of weapons control and release is of concern to C^3I planners. We will attempt to use simulation and analytical modeling to develop the doctrine needed to ensure proper weapons release and ordnance safety. Technology assessment techniques are also being employed to assist in this area.

Although our theoretical knowledge in communications networks probably exceeds the knowledge we possess in the other fields being discussed, we must still devise network management arrangements suitable for this program and prove our concepts by simulation and modeling.

The term "battle management" itself implies that the entire range of C^3I technology is capable of performing the tasks previously mentioned. We therefore would require a means to achieve real-time resource allocation. Adaptive algorithms appear to be the desired research goal.

The SDI program has identified five priority technologies for investigation, two of which are of special concern to C^3I. The discrimination and tracking of numerous reentry vehicles, decoys and other threats during midcourse and high-angle reentry are high on the list of needed demonstrations; the automated preparation, testing, and proving of battle management software are included as high priority issues. In sum, the vital C^3I aspects associated with SDI are of prime concern to the DOD and suitable research is being undertaken.

We have discussed many aspects of planning and of the architectural approach to ensure that our plans are consistent, effective, and directed toward sound and reasonable goals. But as we all know, having a plan, even a perfect plan, is only a small part of achieving the capabilities we need. The next step is to be able to stick to the plan. To accomplish tangible results we need to achieve program stability and realistic costing. Getting the "bugs" out before production is important to all programs; in the case of space segments it is crucial. Better management for such items as technological change, front-end funding for test hardware, and quality assurance can go a long way to advance our space programs. Your support in helping DOD provide the space systems we need for our national security is solicited and appreciated.

ARMS CONTROL IN SPACE:

Preserving Critical Strategic Space Systems Without Weapons In Space

Robert M. Bowman

The United States is the world leader in space technology. The current debate concerns how we can use this advantage to enhance our national security. At the center of this debate is a renewal of the whole question of ballistic missile defense, an issue that was once thought to have been put to rest by the Antiballistic Missile (ABM) Treaty.

Most strategic thinkers accept the fact that technology and military power in themselves cannot prevent nuclear war and provide for our security. They understand that security depends on a rational mix of the application of technology to military power and the use of diplomacy to arms control and disarmament.

Arms control agreements in the recent past have resulted primarily in shifting the arms race to weapons not covered. Supporters of the nuclear arms freeze point to its universality as one of its greatest virtues. Rather than to limit or ban specific weapons (as has been done in the past), it attempts to put a stop to a whole range of activities connected with a broad class of weapons. It is true that because of the breadth of the proposal, verification of it would be fairly straightforward. But there are many other types of weapons that would not be covered. It is likely that a freeze, as presently proposed, would foreclose the arms race in the nuclear arena, only to have it accelerate in other areas such as space weaponry.

The primary purpose for arms control is to reduce the chance of war. (Secondary benefits, like reducing the cost of preparing for war or reducing the destructiveness of war, have been rendered less important in this nuclear age.) This paper attempts to show that preventing an arms race in space is critical to the primary arms control objective. Allowing the arms race in space to continue would greatly increase the danger that nuclear weapons, even those remaining after a freeze, would be used. In addition, the paper proposes concrete treaty initiatives that would enhance the security of the United States. To explain the role of space weapons in the risk of war requires a review of recent developments in strategic thought.

HISTORICAL BACKGROUND

Public support for the nuclear arms freeze was greatly aided by the American people's perception that we had suffered a profound and dangerous change in national policy and military strategy. Though divided over Vietnam, our country was for years relatively united on strategic matters. The motto of the Strategic Air Command, "Peace is our Profession", expressed the prevailing conception of our entire military effort. The military services were rather selective in the weapons they developed and deployed, choosing those that contributed to stability and rejecting those that were destabilizing and would hurt, rather than help, the job of keeping the peace. A minority of people have cared little for strategy and yearned for whatever weaponry technology would allow, but, until recently, this minority has had little influence.

Central to our military philosophy has been the subjection of weaponry to strategy. Our greatest success in this regard was the conclusion of the ABM Treaty in 1972. The United States and the Soviet Union both recognized that ABM systems were potentially destabilizing. Of course, agreement was aided by the fact that such weapons were expensive and technically risky and that neither side perceived the possibility of emerging from an ABM race with a decided advantage. Still, the agreement was an important validation of the principle of maintaining stability in order to prevent war.

The negotiations that led to this success were at the same time our greatest failure in the subjection of weaponry to strategy, in that we refused also to outlaw multiple independently targetable reentry vehicles (MIRVs). MIRVs have led directly to our current relatively unstable situation by making a first strike theoretically advantageous. As long as there was only one warhead on each intercontinental ballistic missile (ICBM), it would take at least one ICBM to kill an ICBM. Actually, because accuracy and reliability are not perfect, the kill probability is always considerably less than one; it is about 0.6 for the new generation of highly accurate missiles. This means that if one side launches 1,000 ICBMs against 1,000 of the enemy's, the attacker will destroy about 600. If both sides had 1,000 to start with, the attacker would be left with none, while his opponent would be left with 400 to do with as he pleased. Under such circumstances it is unlikely that either side would be foolish enough to attack the other. This is a very stable situation.

With MIRVs, however, a single ICBM can send two of its warheads to each of several enemy silos, thereby destroying a number of opposing ICBMs. The newest generation can achieve about a 5-to-1 kill ratio. Thus the one to strike first can theoretically emerge with a big advantage. This destabilizing effect of MIRVs was recognized at the time, and an agreement banning them could easily have been reached. But we were blinded by our technological superiority and refused to include MIRVs in the treaty. Instead, we went ahead with MIRVs on our missiles. When, a few years later, the Soviets followed suit, we discovered that we were less secure than before. We had created for ourselves what we now call the "window of vulnerability", something impossible without MIRV.

The MX was supposed to solve that problem by being highly survivable. Survivability is a highly stabilizing feature, making it possible to "ride out" a first strike and retain a strong retaliatory force. But while we were at it, we couldn't help throwing into our new missile all the goodies that advanced technology makes possible, including a highly accurate guidance system that gives the MX a potential first-strike, or "silo-busting," capability. When the survivability of the MX proved too expensive and difficult to achieve, we were left with what we have today: a system with no more survivability than its predecessors, but with much greater accuracy. Such a weapon is useful only in a first strike and thus is provocative to the other side and highly destabilizing. The MX was a misfit in our deterrent strategy. Gradually, our strategy has changed to fit our weapons. Meanwhile, war has been avoided largely because of the stabilizing influence of space systems.

THE EFFECT OF SPACE SYSTEMS ON NUCLEAR STRATEGY

The military surveillance systems of the United States and the Soviet Union have until now contributed immeasurably to peace by denying the element of surprise to an attacker and eliminating any advantage of a first strike. By giving each side the knowledge that it could not be taken by surprise, the space systems have reduced the pressures for preemptive strikes and led to a considerable lessening of tension. Space systems provide time for analysis, confirmation, consultation, and deliberation, and have made hair-trigger responses unnecessary. They have also provided the technical means of verification that have made arms control possible.

But now we are at a juncture. Space can continue to provide even greater benefits and solutions, or it can become a massive and perhaps decisive part of the problem. What has changed? Our military forces have become more and more dependent on space systems, not only for surveillance and warning, but also for communications, targeting, weather, terrain mapping, navigation, and other "force multiplier" support functions.

Once policy and strategy had been changed to accommodate the MX, and a protracted, limited nuclear exchange scenario had been adopted, military strategists realized, to their horror, that the space systems on which their "war-fighting" capability depended were strictly peacetime systems, designed to support a strategy of deterrence and not survivable in a conflict situation. The function for which they were designed was to give early and unequivocal warning of an enemy attack and to support the launching of a retaliatory strike. It was assumed that any attempt to destroy our satellites would constitute warning that an attack was either under way or imminent and would put in motion the retaliatory machinery. The obvious inability of the United States to keep a full set of satellite systems operating for more than a few hours into a nuclear war did not seem to matter.

The peacetime nature of our space assets was reinforced by the national decision to compel the Air Force to design all its new satellites for launch on the shuttle. Over the vehement opposition of the military, the shuttle was crammed down the throats of program officers responsible for operational satellite systems. At the time, this was deemed necessary in order to justify the shuttle financially. Later in the development of the shuttle, only the political and financial support of the Air Force saved the program from cancellation. Time and again, the Congress was forced to ante up more money to complete the shuttle development because the Air Force was totally dependent upon it. The dependence had been thrust upon the Air Force to create just this situation.

The shuttle, of course, is so vulnerable to attack, both in orbit and on the ground, and its two coastal launching sites are so vulnerable, that it is inconceivable that the United States could launch any new or replacement satellites once any hostilities had broken out. Two World War II submarines (or rowboats for that matter) or even two terrorists with hand grenades or mortars could totally wipe out the country's launch capability in seconds. Similarly vulnerable is our capability to communicate with the shuttle and to get data back from it or from any of our other satellites. Even the new multibillion-dollar Consolidated Space Operations Center (CSOC) which the Air Force is building in Colorado Springs will be vulnerable to attack or sabotage by the most meager of forces.

It is therefore ironic that while national decisions were being made that irretrievably limit our space capabilities to the peacetime tripwire role for which they had been designed, simultaneously other decisions were being made to spend hundreds of billions for weapons which are useful only in a protracted nuclear war, but which depend heavily on space systems not designed for that purpose.

One choice available when this dichotomy was recognized was to abandon the MX and other protracted war weapons and to stick with a policy of war prevention. That choice was not made. Once a system gets to a certain point in the pipeline, it is extremely difficult to kill (witness the B-1, rising from the ashes like a phoenix). The choice selected was to attempt to upgrade the nation's space capabilities to give them a war-fighting capability.

Increasing the survivability of satellites by hardening them against attack was given much lip service and several millions of dollars, but little was accomplished. Providing survivable launch capability by returning to expendable launch vehicles was considered for selected systems. But most of the effort went into a program to develop a US antisatellite (ASAT) system to match that of the Soviets. The rationale evidently was that if they are going to threaten our satellites, then we will threaten theirs. The fact that we are much more dependent on our satellites for command and control of strategic forces than they are did not prevent us from making such a decision.

We have now developed an ASAT far more sophisticated, far more capable than that possessed by the Soviets. It was ready to begin operational testing in early 1983 and had a successful booster system test in January 1984. Its first critical test against a target in space has been held up by congressional action and cannot take place before April 1985. ASATs now threaten to negate the beneficial stabilizing influence of surveillance and warning satellites.

For years, our policy was to negotiate a ban on ASAT's if at all possible. In 1975 we dismantled the ASAT system that we had had operationally deployed since 1963. It had been a nuclear-tipped system, far too indiscriminate in its destructive power and inconsistent with our treaty obligations. We recognized the fact that we were more secure in a world without ASATs than with them, even if ours were superior to the Soviets'.

This truth is now being ignored. We seem to be intent on surpassing the Soviets in the arms race in space and are therefore beginning to test an ASAT whose deployment (or nondeployment) will be almost impossible to verify. The testing of our ASAT weapon may therefore be an irreversible step that will make it very difficult to return space to the status of a sanctuary for peaceful and nonthreatening military support systems.

As long as there are nuclear weapons and delivery systems for them, the United States and the Soviet Union will need space surveillance systems to provide some measure of stability. To allow those systems to be threatened by antisatellite weapons is reckless and foolhardy. This danger is now being compounded by our unfortunate pursuit of weapons with a first-strike capability.

Some proponents of our new war fighting strategy have invented second-strike scenarios that require silo-busting capability, thereby justifying the MX. Others, however, blatantly talk about situations in which the United States, in their opinion, should strike first, destroying Soviet ICBMs in their silos and Soviet command posts and hardened communications centers. Provided we also abrogate the ABM Treaty, install a point-defense system, and embark on a huge civil defense program involving evacuation of cities, we can, according to these strategists, hope to limit US casualties to as few as 20 million deaths.

There is one minor flaw in this "optimistic" portrayal of victory. It depends on the Soviets, when faced with such a capability, continuing their present policy of requiring committee approval before a nuclear strike can be ordered, a time-consuming procedure. Clearly, if we proceed with the MX, Trident II, and Pershing II, the Soviets, with as little as 4 minutes' warning, will have to go to an automated launch-on-warning procedure. This makes the survival of the United States contingent on the reliability of Soviet computers. Our sophisticated and technologically advanced computer warning system has given many false alarms. One of the recent ones was not identified as false until 6 minutes had elapsed. If the Soviet system did no better, such a fault would bring about the annihilation of the United States.

Administration strategists have the answer to that: "Knock out their surveillance satellites prior to a nuclear attack and they won't have any warning!" I wonder what makes such "strategists" think the Soviets, once blinded, will just sit there and let themselves be decapitated? Herein lies the greatest danger. Once the United States has both a first-strike capability and an ASAT capability, what happens if a Soviet warning satellite is struck by a meteor or suffers a catastrophic electrical failure? Might the Soviets not reasonably assume that we have just destroyed their satellite so that they will not see the attack we are launching against them? Will they not then be likely to give the order to launch a "retaliatory" attack?

First-strike offensive weapons are dangerous to our security. The ASAT is dangerous to our security. Together, they are devastating and are very likely to bring on the war neither we nor the Soviets want—a war neither we nor the Soviets can survive.

WEAPONIZATION OF SPACE: ASAT AND BMD

The militarization of space is an accomplished fact, on both sides. But until recently, the emphasis was on nonweapons applications such as communications, navigation, and surveillance. Now a new phase is beginning, the weaponization of space.

The change has been a gradual one. Military spacecraft still perform stabilizing missions, but they now perform others less benign in nature. The coverage and responsiveness of surveillance systems have improved to the point that they can be used not only to provide strategic intelligence and warning information but also to perform targeting of tactical targets on a real-time basis. Such systems, although not normally thought of as weapons, perform the function of "spotting scope" and perhaps even of "gunsight". Thus they are increasingly being considered a part of the total weapons system they support. Similarly, navigation systems, which originally were only good enough to allow ships to roughly locate themselves in vast ocean reaches, now give position and velocity in three dimensions with astounding accuracy. They are in this way able to help warheads of all kinds navigate to their target, providing ICBMs and submarine-launched ballistic missiles (SLBMs), for example, with potential silo-busting accuracy. They have thus turned strictly retaliatory weapons into potential first-strike weapons, greatly destabilizing the arms race.

These threat-enhancing space systems, having been introduced on both sides, have prompted both sides to pursue ASAT weapons to counter them. Perhaps without realizing the Pandora's box they were opening, both sides have thus embarked on a new and far more dangerous phase of the military use of space, its weaponization.

Although ASATs were originally developed to attack threatening space-based force-multiplier systems, they are now becoming indispensable as necessary precursors and adjuncts to a "Star Wars" space-based ballistic missile defense (BMD) system. Because of the technology overlap between ASAT and BMD, the vital role of ASATs in countering BMD systems, the necessity of anti-ASAT systems to protect the enormous investment represented by space-based BMD, and because of the powerful ASAT capabilities of even primitive "Star Wars" BMD systems, it is probably no longer possible to deal with either ASATs or BMD alone.

One of the weaknesses of the ABM Treaty and the Outer Space Treaty is that neither prohibits ASATs. The development of ASATs is threatening the viability of these treaties. Similarly, no ASAT ban can be effective if the development of BMD systems continues and destroys the ABM Treaty. From an operational military point of view as well as from an arms control point of view, space weapons must be dealt with as a whole.

ASAT technology is infinitely simpler than "Star Wars" technology, and the development of ASAT systems is at a critical stage. The decision about whether to proceed is urgent. But that decision is driven by the prospects for "Star Wars" BMD systems, and therefore (even though the operational deployment of such systems may be decades away) the advisability of pursuing these systems must be determined now. If "Star Wars" weapons are likely to make us more secure, then we should reject any ASAT ban and move to gain operational control of near-Earth space. Conversely, if "Star Wars" weapons are infeasible, unaffordable, or detrimental to our security, we should attempt to negotiate a comprehensive and verifiable ban on all space weapons, including ASATs.

Because of the crucial importance of "Star Wars" BMD systems and their strategic implications, a major portion of this paper will be devoted to them.

"STAR WARS" BMD WEAPONS

What has changed since the United States abandoned Nike-X, Nike-Zeus, Spartan, and Sprint and embraced the ABM Treaty? There have indeed been advances in the technology for such point defenses. We can imagine the possibility of survivable radars to support such systems. The Army's homing overlay experiment showed that with modern infrared homing sensors, it was possible to destroy incoming reentry vehicles without nuclear-tipped interceptors. But these advances are not behind the reevaluation of the prospects for ballistic missile defense. It is, rather, the growing technology to support the possibility of the interception of ICBMs in boost-phase.

Boost-Phase Intercept

Boost-phase intercept has several distinct advantages over BMD operating later in the trajectory. Boosters under power have flaming exhaust tails that are easy to detect and track with infrared sensors, even from satellites 20,000 miles away.

Reentry vehicles are small, relatively cold objects that can be seen only by exotic sensors focused accurately on a small volume of space at relatively close range. Boosters are primarily cans of fuel and, although they are far more durable than satellites, boosters are much more vulnerable than reentry vehicles built especially to withstand the rigors of reentry. Finally, boosters are far fewer in number. A launch of 1,000 boosters will "MIRV" into perhaps 10,000 warheads and 100,000 decoys. It is easy to see that being able to attack ICBMs in the boost phase, rather than having to wait until they are inbound to their targets, changes the whole nature of ballistic missile defense.

Of course, boost-phase intercept has its drawbacks. The boost-phase lasts only a short time (40 to 300 seconds) and occurs very near the launch point. The intercept must therefore occur over enemy territory (or for SLBMs, over the ocean). This complicates the basing of the defensive system considerably.

The problems of boost-phase intercept are well illustrated by Dr. Richard Garwin. He likes to tell about his invention which is technically feasible, requires no new technology, is extremely affordable, and could be quickly implemented. It consists of a machine gun with a red-blooded American manning it standing next to each Soviet missile silo (two per silo for redundancy might be prudent). When the silo cover slides back and the missile emerges, the American squeezes the trigger and shoots the booster full of holes, causing it to explode. The problem with this system, as Garwin points out, is clearly its vulnerability. The Soviets would see us putting it in place. They would have to accede to its being there. And they could eliminate it whenever they chose (probably just prior to launching an attack.)

A booster-phase defense does not have to be stationed on the ground next to the silos. It could be put into space, a few hundred miles above the silos. But the problem of vulnerability remains essentially the same. The Soviets would see us putting the system in place. They would have to accede to its being there. And they could eliminate it (with ASATs or space mines, for example) whenever they chose.

By moving "machine guns" into space, you also introduce a new complication. They can't just stand there, but must orbit the earth at a velocity dependent on the altitude. Any given component (laser battle station, machine gun, or whatever) spends only a small fraction of the time within range of the missile fields where boost phase will occur. This means that (depending on the lethal range of the particular weapons being used) there must be 10 to 30 components in orbit for every one on station. This fact does not negate the technical feasibility of such defenses, but certainly influences the economic trade-offs between the offense and defense. The offense can drive up the number of "Star Wars" battle stations required, and therefore the cost of the defenses, by increasing the number of offensive boosters to be intercepted, by hardening the boosters to decrease the lethal range of each defensive weapon, by modifying the boosters to shorten the vulnerable boost time, or by implementing some combination of these.

Another possible basing mode for boost-phase intercept systems attempts to overcome the enormous vulnerability problems of either Garwin's machine gun or space-based orbital systems. Dr. Edward Teller has proposed a "pop-up" basing mode for his nuclear-pumped x-ray laser "Excalibur" system. In this scheme, the defensive weapons are kept on the surface until needed and are then "popped up" into orbit within range of the boosters. Of course, these surface-based systems cannot be based near the missile fields or, as Garwin points out, they would be just like his machine gun. They would have to be based in friendly territory or in international waters not controlled by the enemy—which puts them quite a distance from the missile fields. (Probably the closest we could get is using a submarine in the Indian Ocean). The difficulty is to get the defensive weapon up into space fast enough so that it can get a clear line of sight over the curve of the Earth before the ICBM leaves the boost-phase. To do this requires an incredibly powerful and efficient rocket. If the offense were to reduce the burn time of the ICBMs even a little, the size of the pop-up rockets (and therefore of the submarines) would have to be increased by a large factor. The ocean soon becomes too shallow to hide the submarine, even when it's sitting on the bottom.

Boost-phase BMD schemes are as old as the space age; new technology, however, has introduced some exciting possibilities. Directed-energy kill mechanisms propagate at the speed of light. And a new generation of technology specialists are eagerly considering the possibilities. But the new technology is also available to the offense for countermeasures and improved offensive weapons. What's more, the old problem remains of finding a survivable basing mode within range of where boost-phase occurs.

Countermeasures to Boost-Phase BMD

There are many effective countermeasures available for each of the candidate systems. Most could be quickly implemented with existing technology at a tiny fraction of the cost of the defensive systems. A few countermeasures have wide applicability against any kind of boost-phase BMD system.

Direct Attack. One of the widely applicable countermeasures is direct attack upon the space-based elements of the defense. Whether or not the kill mechanism is based in space, *all* the proposed systems would be completely dependent on some kind of space-based surveillance and tracking system, space-based battle management computers, or command-and-control satellites to communicate data to and from ground-based computers, and other vulnerable satellite elements. Basing the kill mechanism somewhere else, as with the orbiting mirrors scheme that keeps the laser on the ground in the United States or with the submarine-based "pop-up" systems, does not eliminate the problem of the great vulnerability of the space-based support elements, and these schemes introduce enormous complexities into an already incredibly complicated problem.

Offensive Proliferation. One of the first effects of the attempt by either side to deploy a "Star Wars" system would be the removal of all restraints on the proliferation of offensive systems. Neither the United States nor the Soviet Union was willing to negotiate a limit on its offensive forces until the ABM Treaty put a cap on the defenses those forces would face. SALT I without the ABM Treaty would have been unthinkable. Although the offensive arms race has continued through qualitative changes, MIRVing of missiles, and improvements of accuracy to give counterforce capability, this competition has been conducted under the numerical limits imposed by SALT I and SALT II. Even though the former agreement has expired and the latter has never been ratified by the US Senate, both sides have been keeping their missile forces within the constraints of these agreements. The reason for this restraint is that greater numbers were not necessary to assure a devastating retaliatory capability in the absence of large-scale defenses. A breakout from the ABM Treaty would change all that.

The obvious first response to a "Star Wars" deployment would be a drastic increase in the number of ICBMs, so as to swamp the defense. If the Soviets estimated that a defense we were attempting to deploy would be 50 percent effective, they would rapidly double the size of their offensive missile force. Because military planners on both sides are always conservative and cautious, they tend to overestimate opposing capabilities and underestimate their own. Thus a system that the Soviets feared would be 50 percent effective might actually be only 10 percent effective. The net effect of this escalation would be to increase the likelihood of war. If war did occur nearly twice as many warheads would reach their targets in the United States.

Quick-Burn Boosters. There are many ways in which ICBMs could be modified to reduce their vulnerability to various "Star Wars" weapons. One of the most effective of these would be to change from liquid fuel rockets to quick-burn solid fuel boosters. The effect of this would be to shorten the burn time from 300 seconds (SS-18) to from 40 to 120 seconds (MX). Boosters begin to be vulnerable to high-energy long-wavelength chemical lasers about 30 seconds after launch. Shortening the burn time from 300 seconds to 120 seconds would reduce the length of the vulnerable period from 270 seconds to 90 seconds. This would triple the number of laser battle stations required to shoot down the same number of boosters. It would also greatly complicate the task of the battle management computers.

This countermeasure multiplies the cost of a laser battle station defensive system, but it is even *more* effective against all the other candidate systems. None of the other kill mechanisms can reach down into the atmosphere. They must wait until about 90 seconds after launch to attack a booster as it emerges from the protection of the atmosphere. Short-wavelength lasers, particle beams, and x-ray lasers are all absorbed by even a very thin layer of air and cannot penetrate much below about 70 miles. Kinetic-energy-kill vehicles can fly down into the atmosphere, but as they do so they heat up and their infrared sensors are immediately blinded. Thus a missile like the MX with its 120-second burn time is vulnerable to such systems for only about 30 seconds. If the burn time is shortened even further, so that the boost phase ends before the missile exits the atmosphere, these kill mechanisms are completely negated.

In testimony before Congress, industry experts testified that for a modest increase in cost (10 percent or so) burn times of ICBMs could be reduced to as little as 40 seconds. Were the Soviets to implement this countermeasure after we had invested hundreds of billions in a boost-phase BMD system, they could render our investment totally worthless.

Alternative Offensive Systems. In light of the foregoing arguments, it seems highly improbable that an effective boost-phase ballistic missile defense could ever be deployed. It is not that our technology, ingenuity, and creativity cannot overcome staggering obstacles. They can, but the new technology is also available to the offense for countermeasures and improved offensive weapons that tend to be available more easily, more quickly, and much more affordably than the defenses they must overcome. In the game of countermeasures, counter-countermeasures, counter-counter-counters, and so on, the tremendous destructive power of nuclear weapons gives the offense the advantage. For the offense only has to overcome a small part of the defense to succeed, while success for the defense demands near perfection.

Even if a totally impregnable, invulnerable "Star Wars" system could be deployed, one capable of destroying all ICBMs in flight, it would be of little or no strategic value. Ballistic missiles can also be launched by submarines from fairly short range. These missiles can use trajectories at such low angles that their entire flight, not just the boost-phase, lies within the protective blanket of the atmosphere. The missiles could not be intercepted by any of the "Star Wars" defenses thus far imagined, with the possible exception of the long-wavelength lasers. Nuclear weapons can also be delivered by cruise missiles launched from bombers or submarines. Cruise missiles fly at very low altitude, safe from even the lasers. (No one has yet imagined a "Star Wars" system capable of reaching down into the atmosphere and attacking cruise missiles. If such a thing were to exist, it would also have the capability to be used as an offensive weapon to destroy any target on Earth at will.) Cruise missiles therefore represent an "end run" around any Maginot Line in the sky.

Space weapons proponents say that they would not mind if the Soviets were to put greater reliance on cruise missiles, because they, being slow, do not constitute a first-strike threat. That is not necessarily true. At present we have no means of detecting cruise missiles, much less of defending against them, so we would not even have the 30 minutes' warning we get with ICBMs.

If the objective of a "Star Wars" system is to eliminate the threat by making nuclear weapons "impotent and obsolete," we must also be concerned with other means of delivery. Nuclear weapons can be delivered by light aircraft, barge, sailboat, diplomatic pouch, indeed by any of the ways people smuggle cocaine and marijuana into the country. If we are concerned about nuclear blackmail,then we must consider the threat of pre-emplaced nuclear weapons that could be detonated on command. No "Star Wars" system can eliminate that threat nor can it disarm potential nuclear terrorists. It cannot protect the people of this country from a massive (or even less than massive) surprise attack.

What, then could a "Star Wars" system do? What is a realistic and legitimate objective for such a system? The "Star Wars" debate is (or should be) primarily one of strategy and objectives, not technology.

BMD STRATEGY AND OBJECTIVES

There are four possible objectives for ballistic missile defense.

> First, to replace a policy of deterrence by the threat of retaliation with a policy of assured survival, based on a near-perfect defense against all types of offensive weapons (as proposed by the President in his "Star Wars" speech of 23 March 1983).
>
> Second, to limit the damage to our country should deterrence fail, by reducing the number of warheads that get through.
>
> Third, to complete a disarming first-strike capability by providing a shield against the 5 percent of enemy missiles surviving our MX, Trident II, and Pershing II attack.
>
> Fourth, to enhance deterrence by reducing the vulnerability of our retaliatory offensive forces,

Each of these four objectives results in its own unique set of system requirements and associated technology challenges. They are listed in order of decreasing difficulty. Each also presents its own political and diplomatic challenge. The first objective, in particular, faces the complex problem of managing, in conjunction with the Soviet Union, the transition from the current offense-dominated to a defense-dominated strategy without passing through an unstable situation. The strategy would have to be implemented in such a way that at no time did the combination of offensive and defensive capabilities bring about the situation sought for in the third objective, the disarming first strike. Of course, everyone now agrees that the kind of perfect defense needed for this first objective is impossible. However, if it were possible, it would be exactly like the kind of defense needed for first strike, except that it would have to deal with about 20 times as many targets. There is thus no way to get such a capability without also achieving the capability to complete a first-strike posture by being able to shield oneself from retaliation.

The second possible objective for a BMD system (limiting the damage should deterrence fail) is particularly troublesome. Such an objective is legitimate, provided the system implementing it does not increase the likelihood that deterrence will fail. And because the system requirements are very similar to those for the third objective, the chances of its increasing that likelihood are high. Damage limiting is, essentially, preparing to fight and win (or at least survive) a nuclear war. There is almost unanimous agreement now that a nuclear war cannot be won and must not be fought. Scientists are arguing over whether even people in the Southern Hemisphere, thousands of miles from the battle, can survive. Because it is not clear that damage limiting will do any good, it should not be allowed to increase the likelihood that war will occur in the first place. In addition, abrogation of the ABM Treaty by either side will lead to an enormous offensive buildup. The best military judgment is that attempting to implement a damage-limiting ABM would probably lead to the launching of so many offensive weapons against it that more nuclear weapons would actually reach our soil than would be the case if we maintained the status quo through a mutual nuclear freeze. Therefore, a BMD system for damage limiting makes no sense whatsoever.

The third possible objective for an ABM system is to complete a first-strike capability by being able to shield oneself from retaliation. Since a first strike (which could be called pre-boost-phase defense) might get 95 percent of the adversary's weapons, an ABM system to support this objective would differ in the following respects from an ABM system to do away with the need for retaliation:

- The allowable leakage rate is greater by a factor of 20.
- The total amount of energy required to accomplish the mission is reduced by a factor of 20.
- The speed of engagement (which dictates the speed of operation of battle management computers and the time available for

repointing and retargeting, for example) is reduced by a factor of 20.

- The element of surprise is no longer with the attacker (retaliator) but with the defender (first striker).

These factors make a big difference. Enormous technological shortfalls remain, space systems remain inherently vulnerable, and the problem of a good kill mechanism for boost-phase interception continues unsolved. The "level of impossibility" is undoubtedly lower by an order of magnitude or so. We cannot expect the Soviets to ignore this possible objective if we set out to develop and deploy an ABM system for any purpose.

The final possible objective for ABM is to "enhance deterrence" by protecting offensive weapons and increasing our ability to retaliate. This is, in fact, the current Pentagon justification for the SDI program. It is certainly arguable, in light of the survivability of our triad as a whole, whether deterrence needs enhancing. Perhaps the land-based leg could use some shoring up if we are to keep it, but this could be done by implementing the kind of ground-based point defense allowed by the ABM Treaty. If this is, in fact, our objective, then it can be satisfied without "Star Wars"; without weapons in space; without violating the ABM and Outer Space treaties; without spending $5,000 for every man, woman, and child in the country; and without putting our survival in the hands of computers.

"Star Wars" is far more than is required to enhance deterrence, and far less than is required to replace it. There is no legitimate objective for the kind of program we are currently pursuing.

THE PROSPECT FOR ANTISATELLITE NEGOTIATIONS

The United States cut off negotiations with the Soviet Union aimed at preventing an arms race in space at the time of the Soviet invasion of Afghanistan. Until recently, enamored with the possibilities of high-tech weaponry in space, and engaged in a quixotic quest for a return to strategic superiority, the Reagan administration has refused to resume those negotiations. Then, in response to growing congressional and political pressure, the administration agreed to a Soviet proposal to meet in Vienna in September 1984 to discuss space weapons. For a variety of reasons, the talks never occurred. It is quite possible that, in the postelection period, such meetings will actually take place; whether an agreement can be reached is another matter. If both sides are more interested in blaming the other for failure than in achieving success, little will be accomplished. Clearly some people in both governments are sincerely interested in reaching an agreement, but their motivations and objectives are very different.

It is clear that US willingness to discuss space weapons, after 4 years of intransigence, was due to the following factors:

1. The Tsongas Amendment to the 1984 Defense Authorization Act required such negotiations as a precondition to testing of the new US ASAT against a space target. The 1985 version is weaker in many respects, but still contains a requirement that the administration indicate its willingness to negotiate some limitation on ASAT weapons.

2. The Democratic party made space weapons one of its main issues in the 1984 election, and the administration needed to do something to defuse this issue as well as the larger issue of its general lack of success at arms control.

3. More and more people in government are coming to recognize that preventing an unconstrained arms race in space is vital to the national security of the United States. An Office of Technology Assessment (OTA) Workshop on Arms Control in Space held 30-31 January 1984 revealed differences in philosophy toward arms control, but also a rather broad consensus that verifiable steps could be taken to restrict space weapons in such a way that US security would be enhanced.

The question of how comprehensive a ban is desirable is the main substantive difference between the United States and the Soviet Union. The Soviets, although agreeing to discuss "limitations" on ASATs, would clearly prefer a total ban on all space weapons. The US position seems to be developing along lines that would prevent the development of more capable Soviet systems, while allowing the United States to complete development of its new miniature homing vehicle to be launched by the F-15. This can be accomplished in either of two ways, either by "grandfathering" existing systems or by limiting ASAT capabilities to lower orbits and prohibiting systems capable of reaching geosynchronous or other very high orbits.

Such an approach by the United States would probably satisfy the administration's political objectives. It would even allow the administration to proceed with testing of our ASAT against a target in space. But this approach has absolutely no chance of resulting in an agreement—and an impasse is precisely what some members of the administration would prefer.

While all the critical US strategic satellites are in very high orbits, Soviet communications and early-warning satellites are in highly elliptical "Molniya" orbits which come very close to the earth over the Southern Hemisphere. Either of the two approaches just mentioned would result in most Soviet satellites being threatened by a highly sophisticated system that can strike without warning from anywhere on the earth, while all but a few US low-altitude "spy" satellites (and the shuttle) would be granted permanent sanctuary.

The best way for the administration to show both the Soviet Union and the American public that it is sincere in wanting an agreement would be to immediately join the Soviet moratorium on ASAT testing and to avoid taking positions that are patently inequitable and nonnegotiable. A testing moratorium can be verified and while space weapons might be hidden, their testing can be verified. The rate of approach in rendezvous can be limited to prevent homing systems from being perfected in the guise of civilian applications. The size and power of lasers can be limited and the proximity of orbiting systems to those of other nations can be controlled. There is no doubt that the development of new dedicated ASAT systems can be prevented.

In summary, verifiable treaty agreements can be reached which would greatly enhance the security of the United States and of the Soviet Union by reducing the danger of war. We should end our recalcitrance and pursue such agreements immediately.

SPACE AND ARMS CONTROL: A SKEPTICAL VIEW

Colin S. Gray

The superpower arms competition is reaching out to embrace the heavens because the competitors derive great benefit from space deployments for military purposes. The terrestrial arms competition between the superpowers results from an enduring geopolitical antagonism. The obvious inexorable logic of this tends to be neglected, however, by some of the more starry-eyed advocates of far-reaching measures of arms control in general, and of space-focus arms control régimes in particular.

This paper suggests that it makes no sense to consider space arms control in isolation, abstracted from its proper context in the arms competition as a whole and in the political structure of superpower rivalry. Critics of arms control malpractice over the past fifteen years, the SALT-START-INF era, have noted the strategic absurdity of discussing offense apart from defense, and "strategic" apart from "theater" or "intermediate-range" forces.[1] The United States cannot have a space arms control policy or a space strategy, any more than it can have a maritime, a land, or an air strategy as distinct from national security policy as a whole. Because large-scale war, should it occur, will embrace all arms and all geographical environments, "Combined arms" thinking should pervade US policy-making for arms control as well as US military operational planning.

Space is a unique environment; states do not own it, no one lives there, and its physical properties are certainly sui generic. However, states neither do, nor will, behave in space in ways fundamentally different from their settled habits of mixed cooperation and conflict in the three other geographical dimensions of political engagement.[2] The militarization of space, which is now far advanced and shows no indication of diminishing, creates a major incentive for the development and deployment of ASAT and active DSAT (defense of satellite) capabilities (to the restricted degree to which those two can be distinguished one from the other).

The development and deployment of large terrestrially-based arsenals of long-range missiles which must leave the atmosphere for much of their flight regimes, cannot fail to create powerful incentives to develop and deploy effective countervailing weapon technologies. These would have to be either space-based or, at the least, assisted by support platforms in space. Similarly, the potential deployment of an architecture of ballistic missile defense that has key elements space-based calls for very robust DSAT capability. DSAT is not necessarily synonymous with ASAT, but the technical overlap could be considerable.

Much of what has been said and written in favor of various proposals for space arms control amounts, in truth, to little more than pious nonsense. Pious because unduly uncritical obeisance is paid to an arms control credo that reflects a triumph of hope over experience; and nonsense because the answers or solutions that are provided are, in fact, provided to a problem, really a condition, that has been wrongly defined. The "problem," properly framed, is not to "keep the arms race out of space," or some similar formulation. The problem is either (a) to remove the incentives for (defensive) space weaponization; or (b) to facilitate the effectiveness of defensive space weapons.

ASAT arms control is a lost cause for a wide range of powerfully plausible reasons that will be specified in detail and discussed later. However, the basic reason why the superpowers have developed ASAT weapons is, of course, because they have chosen to provide important, and arguably essential, force multiplier support with space platforms and these are, without doubt, increasingly important. The more important the military assets deployed in space, the greater the incentive, on the one side, to hold them at risk and, on the other side, to provide for their defense—passively and actively.

The arms control process, in my opinion, is unlikely to bring about a military space environment conducive to the best interests of the United States. But arms control schemes could be designed (though not for space systems), that certainly would be helpful for national security—providing they could be negotiated and that the Soviet Union would comply with their terms.

ATTITUDES AND OPINIONS: THE "ARMS CONTROL CULTURE"

The Napoleonic maxim that the moral is to the material as three is to one, could usefully be supplemented by the proposition that the political is to the technical as three is to one. Armaments are, of course, at one level technical; their meaning, at a more significant level, is political. Armaments are not the problem: the problem is the propensity of governments to use them. History, including some very recent history, is littered with technical schemes for the control, and generally reduction, of armaments, schemes as ingenuous as they were politically irrelevant. The lobby for space arms control, (as was said of the Bourbons who were restored by the allied victory over Napoleon) would seem to have learnt nothing and forgotten nothing from historical experience.[3]

It is both bizarre and sad that the current debate about ASAT and the Strategic Defense Initiative (SDI) suggests that the most important question to be asked of space weaponry of different kinds is how best to control it—as if it were ASAT and BMD weapons themselves that were the overriding threats to peace. The non-controversial "enduring truths" about arms control need to be recalled:

- Progress in arms control reflects the quality of political relations. The more radical the military consequences of an arms control regime, the better the political relations required to sustain it.
- As a very general rule, states compete in armaments because they believe they may have to fight each other (i.e., all arms

races are rooted in, and fueled by, politics). The state-to-state conflict systems that could be said to be in most need of the benign medicine of arms control are denied that medicine precisely by the facts of political conflict. This is called the "arms control paradox."

- The historical record of arms control in action shows that arms control regimes have either been essentially trivial, or harmful in their effects upon international security.[4] The most important item in the arms control credo is the belief that arms control can reduce the risk of war occurring. All things are possible, so one hesitates to assert that this belief is wholly ill-founded. However, the belief that arms control can reduce the risks of war occurring is probably wrong and certainly is without plausible, historical foundation. Arms control theory may well have stumbled into a tautology. Arms control arrangements which seem to dampen proclivities to bellicosity are, in fact, the products of combined political wills to provide tangible expression of a decreased inclination to fight. This is not to deny the possibility, indeed the probability, that arms control can provide positive feedback for its political sustenance. Nonetheless, the notion that an arms control regime could serve, in some respects, as a barrier against war, is a logical absurdity. Politics is the deciding factor, not the technical details of military posture nor even relative military power.[5]

- Western democracies, in the 1920s, the 1930s, and today have proved to be incapable of prudent management of any major aspect of the arms control process—negotiation of terms of agreement, coping with treaty non-compliance by authoritarian treaty signatories, or adequate but treaty-compatible defense preparation. There is no reason to believe that the United States would be able to manage a new space arms control regime any more prudently than it managed naval arms control in the 1920s and 1930s, or SALT since the early 1970s.

There is in the United States today what one could term an "arms control culture." that is to say there is a body of socially transmitted culture that inclines those so encultured to believe, macroscopically, that defense problems are really arms control problems and, microscopically, that the responsible citizen's first duty vis-à-vis a particular weapon is to try to prevent its deployment, control it, or abolish it. For the sake of justice in debate, it is only right to note, as Ralph Lapp argued at book length,[6] that there is also a "weapons culture" in the United States. Both world views, or cultures, are potentially harmful to the national security.

Arms control need not make us more secure, just as weapons need not make us stronger. In the process of arguing that an arms control culture is framing false choices for US national security policy with respect to projects for space arms control, I do not intend to imply enthusiasm for deployment of any and every weapon that American engineers are able to construct. Folly in indiscriminate weapon accumulation, however, does not justify folly in arms control advocacy.

Behind the emerging debate over space arms control are general attitudes towards the value of an arms control process.[7] As I have suggested strongly above there are what may be termed enduring "structural" realities pertaining to arms control. These realities limit genuine security achievement in that realm,[8] and ensure that political conditions, not technical relations in armament, comprise the more independent variable.

If optimism over the prospects for new space arms control regimes has not been sufficiently dampened by the arguments presented thus far, it is time to introduce two additional levels of difficulty. The two levels function synergistically for malign effect. If "Problem Level One" is the character of interstate relations and the highly plausible proposition that arms control follows improved political relations as trade follows the flag, then "Problem Level Two" is the political (and strategic) culture and style of the relevant participants in the arms control process. "Problem Level Three" comprises the technical characteristics of the candidate weapon agenda for control.

"Level Three" issues are deferred for treatment in the ASAT and SDI sections below. At this juncture it is necessary to introduce some of the salient characteristics of Soviet and American political culture and style. Political and strategic culture is not the shifting product of particular people who are struggling pragmatically to solve problems on the basis of necessarily very imperfect information. Culture comprises concepts, attitudes, habits, and skills that characterize the way a community defines its tasks, prefers to approach them, distinguishes their elements, and seeks to accomplish them.[9] Therefore, this analysis examines space arms control between distinctively Soviet and American competitors.

No matter where one stands regarding particular space arms control ideas, there can be no evading the unfortunate facts that the Soviet Union has a well documented history of cheating on solemn agreements,[10] and the United States has a no less well documented history of practical, if not formal, acquiescence in such Soviet cheating. Before delving into the arguments over ASAT control and the future of the ABM Treaty of 1972, one should recognize that the pertinent structure of the situation vis-à-vis ASAT arms control looks distinctly unpromising. To summarize:

> It is Russian/Soviet cultural style not to permit legal niceties to stand in the way of desired military program deployments. Moreover, the Soviet Union has *demonstrated* a willingness to evade the plain meaning and purpose of arms control agreements both in ways that have military significance (the SS-19, the SS-X-25, telemetry encryption, Moscow ABM system upgrades, underground nuclear test yields) and in ways that do not (Limited Nuclear Test Ban violations [persistent venting], "yellow rain," and so on).
>
> Noncompliance with a space arms control regime would be unusually difficult to verify, because of the technical similarity of "scientific" and military missions, the "piggyback" possibility for illicit hardware, the impracticality of space-platform inspection, and the residual ASAT capability of strategic offensive and defensive missile forces.
>
> The potential military payoff from ASAT Treaty noncompliance is very high indeed, given the facts that the United States has deployed well under a hundred satellites that the Soviet Union could be motivated to target, and that the United States does not have a production line approach to satellite provision. The United States is not at all well positioned to replace

combat losses among space platforms. This is the vice of the virtue of superior station-keeping qualities—the US approach to its space system architecture is highly efficient *in peacetime*.

> The United States has yet to call a halt to any treaty regime (or carry through on threats to do so) on grounds of unsatisfactory Soviet responses to noncompliance concerns. And yet the SS-19 made a nonsense of the Interim Agreement on Strategic Offensive Arms of SALT I, the SS-X-25 and missile test encryption are fundamentally incompatible with the plain American intent in SALT II, and the Abalokova radar lends itself to no plausible technical interpretation other than that it is intended to "close the back door" as vital, long lead time infrastructure for nationwide BMD coverage.[11]

The key issue is not really verification of space treaty compliance or noncompliance. Instead, the central policy issue is what the US Government would have the political courage to do in the likely event of technically plausible evidence of Soviet non-compliance being provided. A background consideration for the US policy debate today over ASAT arms control is the fact that the Soviet Union has not complied—at least in ways compatible with US understanding of the purposes and plain meaning of agreements—with virtually any arms control regime to which she has been a signatory. What would be the basis for arguing either that the Soviet Union would behave differently "next time," or that the United States really would insist upon a very high quality of Soviet treaty compliance, and would be prepared to withdraw in the event of a persistence in unsatisfactory Soviet performance? Soviet noncompliance, or very uncertain compliance, with a SALT or START regime is judged by many people—wrongly, in my view—to be tolerable because the sheer quantity of weaponry permitted both sides makes for an inherently robust military balance. By way of contrast, the balance in capability to use and deny outer space for military purposes is inherently delicate, given the low numbers of important platforms deployed.

ASAT ARMS CONTROL: FOR AND AGAINST

The American "arms control culture," for very understandable reasons, has served strong notice that keeping weapons out of space has become its first priority.[12] Even the MX/ *Peacekeeper* ICBM fades in significance compared with the offenses that space weaponization is projected to commit against the arms control credo. It is difficult to avoid miscategorizing particular individuals, and particular arguments, concerning space arms control. A central complication is that though the debate over ASAT and ASAT arms control is to a degree distinctive, it has major implications for the SDI. Different opponents and proponents of the SDI have a variety of strategic desiderata in mind. At some considerable risk of omitting important variants of attitude and opinion, it is worth noting the following points:

- One can find arguments against ASAT arms control of particular kinds technically persuasive regardless of one's position on the desirability of the United States proceeding to deploy ASAT weapons.
- It may be just possible to favor some ASAT control ideas but also to favor the SDI—provided the SDI is precluded from proceeding towards a system architecture capable of engaging targets in boost, post-boost, or mid-course flight regimes.
- Anyone concerned seriously to protect high-leverage technical possibilities for the SDI, involving orbital deployment of key sensors and possibly of actual weapon platforms, prudently cannot support any ASAT control ideas that proceed beyond the "rules of the road," or "prohibited acts/behavior," genus.[13]

ASAT control prospects today have to be considered both on their own terms and in relation to a US (and Soviet) freedom of policy action in the future. To ensure that I am not accused of having a hidden (SDI) agenda lurking behind an ostensible discussion of ASAT, I readily acknowledge that SDI protection logically dominates this discussion. However, as will be made plain, the case for ASAT arms control would fall for reason of its own weaknesses even if no SDI arguments of policy relevance existed.

Stated as directly as possible, the SDI—properly constructed so as to include air defense and civil defense—offers the only half-way plausible prospect for reducing very dramatically the quantity of nuclear threat to American society. If there were some attractive political, or radically less expensive technical, means available to the same end, I would argue for them very forcefully. Pending some historically unprecedented transformation in the character or terms of international political discourse, the SDI—technical uncertainties and novel strategic problems admitted—offers the only path leading towards our living in much greater safety that may (or may not) be available. ASAT arms control, like the ABM Treaty, easily could place at fatal legal and political risk the prospect for eventual societal defense on a comprehensive (though not literally impermeable) scale. Ergo, a very great deal is, or could be, at stake in the contemporary policy controversy over ASAT arms control.

The case for ASAT arms control, at least superficially, would be stronger than it is today were it possible to design an ASAT control regime to accomplish useful things. It is far from self-evident that ASAT arms control could accomplish what its more single-minded proponents claim for it unless, of course, they have a "hidden agenda" to inhibit SDI development. In the United States at least ASAT arms control would likely achieve this very effectively indeed.

What is the argument for ASAT arms control?[14] First, at the most general level, there is the claim that it can be done. This is more than a little reminiscent of the allegations of "technology push" by weapon scientists and engineers who foist their new weapons on policy makers.[15] It is argued that there is a narrow "window of opportunity," a "last clear chance" before ASAT deployment becomes, at best, vastly more difficult to arrest or reverse and, at worst, literally unstoppable.

Reference is made to the late 1960s US policy design for SALT I, to the allegedly missed opportunity of preventing MIRV deployment. It is believed that, in that instance, the United States chose to gain a near-term military advantage at the plainly predictable price of future strategic instability. ASAT, like MIRV, so we are told, is a development that the United States will have leisure to regret. Naturally, if the more dire predictions of ASAT prove to be accurate, that leisure period might be painfully curtailed.

The answer to this argument is that one should not do something simply because it can be done. It is a long way from established fact that MIRV truly was negotiable. Moreover, nothing could be further from the truth than the claim that the United States is pressing ahead towards deployment of a technically superior ASAT (with the Air-Launched Miniature Homing Vehicle [ALMHV]) in search of a quick advantage, heedless of the strategic consequences. Apart from the other reasons why an ASAT control treaty would be a snare and a delusion, the certainty that such a treaty would place a fatal political-legal ambush down the road for SDI development suffices to condemn it.

Second, the United States is, supposedly, more dependent upon space platforms than is the Soviet Union, so ASAT arms control, even of a modest character, would have to function to the net US advantage. There are two obvious problems with this argument. The first is evidential: the Soviet Union is making heavy, and increasing, use of space for important military functions.[16] This is not to deny that in some crude quantitative sense the Soviet Union may be less dependent on space assets than is the United States, but one should not neglect possible operational contexts, nor the character of Soviet military doctrine. The side that seizes the strategic initiative is likely to have its space-based assets in better condition than the side that is placed in the strike-back position. Also, the war-fighting, "classical strategy," orientation of Soviet military doctrine may render some Soviet military space assets—for intelligence gathering and navigational assistance for restrike—of more critical significance than might otherwise be appreciated.[17]

The second difficulty with the argument for the net American advantage in ASAT weapon control is very much a matter of common sense. The Soviet Union has no record of endorsing, knowingly, an arms control, or any other kind of treaty regime that must work to its net disadvantage. As the Defense Intelligence Agency wrote in a recent report: "the idea of maintaining a balance or 'staying even' with a foe is alien to Soviet military thought."[18] Arms control, to succeed or to endure politically, must be a non zero-sum game. However, the apparent strength and the nature of Soviet interest in ASAT arms control should be explored rigorously. Are they fearful of what the absence of ASAT control could imply for a US SDI program that threatens the integrity of their strategy? Or, dare one suggest, could it be that they can contemplate an ASAT control regime with equanimity because they do not expect to comply with it strictly?

Third, in favor of ASAT arms control it is argued that space-based surveillance assets of different kinds, and space-based communication relays, are critically important for "stability." Therefore, any military deployment which would place those assets at risk, and particularly at very prompt risk, would promote instability.

A variety of offsetting arguments should be noted. Only a very optimistic person could feel confident that any character of ASAT control treaty actually would succeed in removing technically reliable threats to US space platforms. Also, first-strike planners would have to worry that ASAT assault upon critical space platforms at very different orbital altitudes would sound a warning bell rather than blind and paralyze. The superpowers are not, and are unlikely ever to become, totally dependent upon space platforms for early warning, more general surveillance, or for long-range communications. There are technical alternatives today, and there will be alternatives tomorrow. Finally, it is just too glib to suggest, as has Daniel Deudney, that "The Archduke Francis Ferdinand of World War III may well be a critical Soviet reconnaissance satellite hit by a piece of space junk during a crisis."[19] If twelve pieces of space junk hit twelve important satellites within a 48-hour period during a very acute crisis, Deudney's idea might have some limited merit (twelve very "stealthy" space mines, perhaps?)

Fourth, many ASAT arms control proponents are focussing upon ASAT as the tip of a space weapons iceberg that carries, in their view, the promise of promoting strategic instability. These people are correct in believing that ASAT as a policy issue today is critically important for the political feasibility of a future endeavor to deploy space-based defenses for society-wide protection.

The arguments against ASAT arms control introduced in this discussion may be summarized as follows:

First, an ASAT treaty cannot usefully "bound the threat" to US space systems. If "ASAT capability relates to all systems capable of damaging, destroying or otherwise interrupting the functioning of satellites,"[20] the threat includes interceptor vehicles (of different kinds, with a variety of possible kill mechanisms). Variously based directed-energy weapons, variously based electronic interference with satellite uplinks and downlinks, and weapons targeted against the ground, air, and sea-based infrastructure for interpretation and relay of satellite data traffic to ultimate users are all potential threats.[21]

The more valuable US space systems can be protected, to a degree, by hardening against nuclear and (some) directed energy threats; by provision of limited maneuver options to "break track;" by "stealthy" design, in some cases; by suitable choices for frequency of transmission; by selection of orbits that cannot be reached rapidly; by storage of spares in obscure orbits; by greater autonomy (from ground control) in operation; and by more extensive cross-linking within satellite constellations (again, of course, where feasible—for NAVSTAR Global Positioning System, for a leading example). No ASAT control treaty can do anything to protect a ground-based infrastructure that is not suitably dispersed, hardened, or defended. Overall, one should not neglect the attack planner's dilemma that ASAT assault against critical early-warning and strategic communication satellites in geosynchronous orbit, on a militarily useful scale, would be akin to a declaration of war and would certainly have dramatic DEFCON implications for force generation.

Second, an ASAT control treaty would be reliably verifiable only in the trivial sense that known ASAT-dedicated deployed hardware could be monitored. Aside from the small complication that the Soviet Union does not own to a dedicated ASAT weapon, there is no way that anything even approaching the full range of ASAT capability, broadly understood (to include electronic warfare), could be verified. Even with respect to the most obvious and visible of ASAT capabilities, ICBM-carried interceptor vehicles, a US government report states as follows:

> ... Andropov's pledge concerning a unilateral ASAT moratorium is meaningless, for the Soviets can continue to test them, disguised as scientific research satellites, regardless of any treaty.[22]

Third, any ASAT control treaty beyond the innocuous could hardly fail to work to the net US disadvantage. As was suggested above, the Soviet Union would have a large incentive to cheat. Cheating on only a modest scale could reap militarily significant payoffs, cheating would be technically all too feasible, and the United States, up to this point, has tolerated cheating. The United States does not develop and test new technology right on the margin of arguable treaty compliance: the Soviet Union does, and then goes a little further.

It should be recalled that the Soviet Union, unlike the United States, does not have a truly civilian space program. In the United States an ASAT treaty would be likely to have the political effect of discouraging expensive programs intended to provide physically for satellite survivability.[23]

Given the long Soviet record of not permitting military requirements to be affected negatively by arms control agreements, one need not be blessed with the gift of prophecy to predict that an ASAT treaty would erode, and probably halt, US momentum in ASAT technical developments that could be weaponized rapidly. For example, the F-15/ALMHV ASAT program requires a great deal of further test activity. A moratorium on testing, offered as a "good faith" gesture to improve the climate for negotiations, could have a devastating impact upon program momentum. A moratorium would have scarcely any impact upon the true scope and depth of all kinds of Soviet ASAT capability; and would discourage the US government from investing scarce dollars in expensive measures to enhance the survivability of space platforms.

Fourth, the United States has a major interest in denying Soviet spacecraft a free ride for their force multiplier missions in aid of strategic-missile, ground, naval, and air forces. Soviet doctrine calls for an endeavor to effect a favorable alteration in the correlation of forces at the outset of a war. However, the Soviet theory of war is focused on the campaign rather than the single battle. It is important for deterrence that Soviet defense planners anticipate being denied the services of ocean surveillance, navigation, and communication satellites. The loss of orbital eyes and ears should complicate the Soviet task of attack assessment for restrike purposes; the loss of RORSAT and EORSAT platforms could be critically significant, given the importance of seaborne power projection in global conflict to the maritime alliance of the West; and the loss of GLONASS[24] navigation satellites should impair the military effectiveness of all Soviet user organizations.

Fifth, ASAT arms control beyond the very trivial, or the short-lived, is not compatible with the freedom of development, testing and deployment action that serious commitment to the SDI requires. ASAT capability, on a large scale, comes as a by-product of, or bonus from, boost, post-boost, and mid-course BMD weaponry. The Homing Overlay Experiment (HOE) of the US Army, for example, formally speaking was a BMD test. But, a HOE-derived weapon that has some capability against warheads would have to be much more impressive in action against satellites (in low earth orbit).

The idea has been mooted that a space arms control regime could be negotiated which would have a lifespan of possibly five years. This, it is suggested, would have zero impact on the SDI, yet would provide the political cover of the positive arms control record on which the US Congress may insist. History shows that both the United States and the Soviet Union have a way of becoming fast bound by the diplomatic record that is established. A five-year, no-space-weapon regime, for example, could affect profoundly the budgetary politics of the SDI during those five years; certainly would generate a "save the temporary treaty" lobby; and would, in practice, be exceedingly difficult to switch off when the five years had elapsed. Proponents of the concept of a limited-term agreement are, of course, aware of these political facts of life.

ARMS CONTROL, DISARMAMENT, AND THE SDI

President Reagan's SDI should be approached as a challenge *for* arms control, rather than as a challenge to arms control. The sacred cows of arms control that the SDI may reduce to hamburger amount to little more substantial than an obsolete theory of stable deterrence and an incorrect theory of arms race dynamics. A great deal, though certainly not all, of the more root-and-branch philosophical objection to the SDI really is an attempt to turn the military-technological clock back to the Great Simplicity of an allegedly technology-mandated condition of mutual assured societal destruction, vintage 1966–68.[25] Efforts to evade or transcend society's vulnerability be they through refinements to offensive targeting plans or through new active defense technologies, are condemned as both doomed to fail and potentially dangerous on account of the self-delusions that they may foster among the gullible.[26]

Some people are seeking to use arms control diplomacy to erect political-legal barriers to technological progress in BMD. It is not a sin against stability to endeavor to protect the American people. The official US concept of strategic stability today refers not at all to capabilities to inflict massive societal damage. It does not embrace the bizarre notion that international security is promoted by the Soviet Union enjoying unrestricted offensive-weapon access to American society. A condition of stable deterrence is one wherein Soviet leaders anticipate the defeat of their strategy. Such a condition, be it noted, is all too compatible with a Soviet ability to defeat the United States in US terms. I have believed for some time that there is an instability in deterrence fostered by the potentially paralyzing self-deterrent consequences of the American condition of an undefended homeland.[27]

To date, official spokesmen for the SDI have shown great respect for the ABM Treaty of 1972. However, opponents of the SDI have launched a "National Campaign to Save the ABM Treaty." Rational and even-tempered discussion of the ABM Treaty is difficult to achieve, because for standard-bearers for rival schools of doctrine, it is a symbolic (if not quasi-theological), as well as a substantive issue. Minds are not open on the subject of the ABM Treaty. With malice towards none, save Soviet noncompliers, the following should be underscored:

- The ABM Treaty rests upon, and was believed by Americans to promote, a particular theory of stable deterrence that has been rejected in Washington and which never was authoritative in Moscow.

- We lack consensus among ourselves on "what drives the arms race." But we do know, *for certain*, that arresting legally the deployment of BMD weaponry did not slow the arms race with reference to encouraging any noticeable slackening of Soviet effort in the field of new, more counterforce-capable weapon deployments.

- The ABM Treaty was negotiated by the United States in the context of very well publicized expectations of relatively near-term conclusion of an enduring offensive-forces control regime with terms conducive to (American ideas on) the stability of deterrence. Those expectations were not well founded.

- The ABM Treaty, like all arms control regimes, was the product of a supportive climate of political relations. That climate changed, leaving a rump regime.

- In 1972 technologies which are the key to the feasibility of high-leverage, multilayered defense were not on the horizon. Arms control regimes tend to be technology-specific, just as the strategic theories that they express, or are believed to express, are technology-specific. As technological circumstances, expectations and not-implausible possibilities alter, so must their doctrinal and policy referents.

Critics who assert that the SDI may place the ABM Treaty in peril are correct. One could add that Soviet non-compliance should also place the Treaty in peril, but the Reagan administration seems reluctant to make that argument bear heavy political traffic. The ultimate goal of the SDI, as President Reagan has stated and restated unequivocally, is to provide nationwide defense that would render Soviet offensive nuclear weapons "impotent and obsolete."[28] Article I of the ABM Treaty similarly is unequivocal:

> Each Party undertakes not to deploy ABM systems for the defense of the territory of its country and not to provide the base for such a defense . . .[29]

It is possible that for a variety of political, economic, and technological reasons the United States may decide either not to deploy BMD weaponry of any kind, or to deploy only a terminal BMD system for endoatmospheric defense of some hard-point targets. In those circumstances, the ABM Treaty poses no barrier to deployment, or would need to be modified only in very modest ways.

Furthermore, a considerable amount of SDI development and testing activity could be conducted were the US government willing to endorse some expediently permissive interpretations of Treaty language and to side-step what many people do now, and would in the future, regard as a plain intention to prohibit. To take the most obvious generic example, the United States is not bound in any way by treaty vis-à-vis development, test, or deployment of ASAT capability. The United States could produce an overdesigned mix of nominally ASAT systems.

In practice, even if the United States were determined not to offer very serious offense to Soviet and domestic sensitivities regarding the bounds of treaty-compliant behavior, considerable useful leeway for BMD development and testing could be found through sensibly self-serving interpretation of key words and phrases in the Treaty, and through exploitation of the absence of any legal restraint on ASAT and ATBM weapons. Article V of the Treaty says that

> Each Party undertakes not to develop, test, or deploy ABM systems or components which are sea-based, air-based, or mobile land-based.[30]

But, what constitutes *development?* And what constitutes a *mobile* system *component?* The examples could be multiplied that lack precise definition.[31] The point is that should the United States decide, (for reasons of politics or for fear of near-term Soviet "breakout" as contrasted with the contemporary reality of Soviet "creep-out" potential) to seek to live with an unmodified ABM Treaty for as long as it is able, there are many ambiguities that could be exploited in the Treaty. There are ambiguities in the associated diplomatic record as well, not to mention the sanction that could be sought with reference to Soviet noncompliance, or very arguable compliance. It need hardly be said that this is not "the American way." I am not recommending that the US government knowingly should affront its cultural preferences in this cynical way.

A more productive, politically defensible, and honorable policy course for the United States would be to reconsider the totality of its approach to strategic arms control. Given what could be at stake over the SDI—the physical protection of the American people in the most direct of senses—and given the plain absence of any attractive, attainable alternatives, the case for removal of ABM Treaty constraints on development, testing, and deployment, would seem virtually to make itself. The ABM Treaty cannot protect the American future; a mature SDI just might.

I do not dismiss the potential value of suitable arms control and disarmament regimes for national and international security. A process of transition to a defense-heavy strategic posture obviously would be facilitated greatly were the Soviet offensive threat to be diminished in quantity and, preferably, frozen in quality. To this end, there are two intimately connected paths to follow: negotiation and the achievement of visible momentum in military programs.

It is almost certainly the case that for the next several years the Soviet Union will be most unfriendly towards the negotiation of any constraints on strategic offensive forces, in isolation, that might lend plausibility to the more expansive American visions of SDI effectiveness. A cooperative, or partially cooperative, defensive transition will have to be earned by the United States.[32] Since the net balance of advantage between US defensive and Soviet offensive weapon technologies ten to twenty years from now is problematical, one cannot assume confidently a secure future for cooperation in a defensive transition.

What one can and should do today is broadly to outline a strategy for arms control assistance for a strategic condition characterized by major defense advantage. Whether or not American negotiators ever will be able to deliver a suitable arms control regime must depend upon currently unpredictable trends in the technical relationship between offense and defense, and on the general state of East-West political relations.

The Soviet Union will agree to reduce its offensive threat if it calculates that in the absence of legal constraints the United States will proceed to deploy a strategic force posture—offense and defense—that will diminish Soviet security non-marginally. What this means is that Soviet leaders will need to believe that their offense will not fare very well against a maturing US SDI, and that their defense will not cope very well with modernized US offensive forces.

Even if Soviet leaders should anticipate being able to sustain a rough equality in the strategic arms competition, still they could well decide that negotiated arms control assistance to the two defensive transitions would be in their best interest. The Soviet Union is not unfriendly to the idea of homeland defense, only to the idea of American homeland defense. Standard geopolitical reasoning may impress upon Soviet leaders the attraction of a strategic context of what would be essentially "sanctuary superpowers." I am not making light of the problems for US and US-allied security of a world where Soviet territory no longer was massively at nuclear risk. However, the focus of this paper is upon space arms control and not upon the difficulties and opportunities that would attend a technologically successful SDI.

Bearing in mind the improbability of a START agreement that would achieve a dramatic scale of negotiated disarmament of nuclear offensive forces, it is appropriate to observe that space-based weapons (directed-energy, projectiles, or rockets) for boost-phase or mid-course BMD, would effect functional disarmament of the long and intermediate-range weapons of the adversary. Actual physical disarmament should follow, if the superpowers appreciated that those means of weapon delivery no longer could penetrate reliably the burgeoning barriers of defense. A final point worth noting about defensive space arms is that they would constitute, de facto, a very robust regime to guard against the possibility of any catalytic war triggered by accidental launch, or launches, of missiles, "friendly" or otherwise.

LOOKING TO THE FUTURE

The bulk of the contemporary public comment advocating space arms control is really very backward-looking. It recommends one or another means of freezing defense technology. Claims by SDI critics to the effect that they favor continuing research on defensive technologies undoubtedly are sincere. Such claims are received with skepticism because generally they do not recognize the necessity of paying a fairly high dollar exploration price to see if effective defense is feasible. So strong, even emotional, is the opposition to the SDI from space arms control lobbyists, that one should be excused doubting whether any degree of SDI technical success would suffice to change the negative attitudes in question. When a person says that he or she would favor strategic defenses that really would defend, but then declines to support a research and development effort adequate to explore the feasibility of suitable systems, one must suspect an unwillingness to be convinced.

Too often, perfect performance is required. In a world with nuclear weapons, only the best defense would be good enough for many people. One sees their point. However, if one could enforce a condition where "leakage" would be low by way of dramatic contrast to the current situation, one would have found a defense not as good as one would like, but a defense which certainly would be good enough to purchase.

Looking to the 1990s and beyond, as we should, the challenge is not to control defensive space arms. Instead it is to design and effect an arms control policy that facilitates the military effectiveness of space arms (weapons deployed in space, deployable rapidly to space, or weapons whose lethal mechanisms are relayed via space platforms). Arms control, properly understood, is not a matter of mindlessly opposing the latest lethal devices. Arms control means stabilizing deterrence for the prevention of war, and canalizing military capability and plans for contingent behavior, in directions conducive to the limitation of damage should war occur. Space systems, weapons and support, that would render the prospective military efficacy of long-range ballistic missiles *and* air-breathing vehicles increasingly problematical, could contribute decisively both to prewar deterrence and to damage limitation. Neither claim can be advanced plausibly in support of the arms control process of the past fifteen years.

ENDNOTES

1. The "umbrella" framework for arms negotiations suggested by President Reagan in the fall of 1984 is, conceptually at least, very promising.

2. For a variety of views on how one should approach space for security purposes, see: Colin S. Gray, "Space is not a Sanctuary," *Survival,* Vol. 25 No. 5 (September/October 1983), pp. 194–204; Daniel Deudney, "Unlocking Space," *Foreign Policy,* No. 53 (Winter 1983–84), pp. 93–113; and Joseph E. Justin, "Space: A Sanctuary, the High Ground, or a Military Theater?" in Uri Ra'anan and Robert L. Pfaltzgraff, Jr., eds., *International Security Dimensions of Space* (Hamden, CT: Archon, 1984), pp. 102–15.

3. A useful historical perspective is provided in Jeffrey Barlow, "Arms Races, Arms Buildups, and War," in Keith B. Payne and Colin S. Gray, eds., *The Nuclear Freeze Controversy* (Cambridge, MA: Abt Books, 1984), pp. 37–55.

4. A powerful recent statement of this case is Henry S. Rowen, "The Old SALT Gang Returns," *The Wall Street Journal,* 2 November 1984, p. 28. Also see Henry Kissinger and Brent Scowcroft's reply in the *Journal* on 12 November, and Rowen's response on 16 November.

5. This thesis is argued persuasively in Stephen Peter Rosen, "Foreign Policy and Nuclear Weapons: The Case for Strategic Defenses," in Samuel P. Huntington, ed., *The Strategic Imperative: New Policies for American Security* (Cambridge, Mass.: Ballinger, 1982), pp. 141–61; and Richard Ned Lebow, "Windows of Opportunity: Do States Jump Through Them?" *International Security,* Vol. 9, No. 1 (Summer 1984), pp. 147–86.

6. See Ralph Lapp, *The Weapons Culture* (New York: Norton, 1968).

7. This important point is well taken in Office of Technology Assessment, *Arms Control in Space: Workshop Proceedings* (Washington, DC: Office of Technology Assessment, US Congress, 1984), pp. 4, 16.

8. See Colin S. Gray "Arms Control: Problems," in R. James Woolsey, ed., *Nuclear Arms: Ethics, Strategy, Politics* (San Francisco, CA: Institute for Contemporary Studies, 1984), pp. 153–69.

9. See Jack Snyder, *The Soviet Strategic Culture: Implications for Limited Nuclear Operations,* R–2145–AF (Santa Monica, CA: Rand,

September 1977); and Colin S. Gray, "American Strategic Culture and Military Performance," unpub. paper (1984).

10. See William Hains, "Breaches of Arms Control Obligations and Their Implications," in Richard Staar, ed., *Arms Control: Myth versus Reality* (Stanford, CA: Hoover Institution, 1984), pp. 134–53; and General Advisory Committee on Arms Control and Disarmament, *A Quarter Century of Soviet Compliance Practices under Arms Control Commitments, 1958–1983, Summary* (Washington, DC: General Advisory Committee on Arms Control and Disarmament, October 1984).

11. See Colin S Gray, "Moscow Is Cheating," *Foreign Policy*, No. 56 (Fall 1984), pp. 141–52.

12. See Thomas K. Longstreth and John E. Pike, *A Report on the Impact of US and Soviet Ballistic Missile Defense Programs on the ABM Treaty* (Washington, DC: National Campaign to Save the ABM Treaty, June 1984); *Arms Control Today*, Vol. 14, No. 6 (July/August 1984), special issue on the Strategic Defense Initiative; Sidney D. Drell, Philip J. Farley, and David Holloway, *The Reagan Strategic Defense Initiative: A Technical, Political, and Arms Control Assessment* (Stanford, CA: Center for International Security and Arms Control, Stanford University, July 1984); and Union of Concerned Scientists, *The Fallacy of Star Wars* (New York: Vintage, 1984).

13. See Office of Technology Assessment, *Arms Control in Space*, pp. 20–1.

14. Useful presentations of the pro-control case are Richard L. Garwin, Kurt Gottfried, and Donald L. Hafner, "Antisatellite Weapons," *Scientific American*, Vol. 250, No. 6 (June 1984), pp. 45–55; and Union of Concerned Scientists, *The Fallacy of Star Wars*, Part III.

15. A recent relevant study emphasizing "policy pull" rather than "technology push" is Jonathan B. Stein, *From H-Bomb to Star Wars: The Politics of Strategic Decision Making* (Lexington, MA: Heath, 1984).

16. An excellent review of Soviet military space activity is in Steven M. Meyer, "Soviet Military Programmes and the 'New High Ground'," *Survival*, Vol. XXV, No. 5 (September/October 1983), pp. 204–15.

17. Soviet doctrine for the military uses of space is examined in Uri Ra'anan, "The Soviet Approach to Space: Personalities and Military Doctrine," in Ra'anan and Pfaltzgraff, eds., *International Security Dimensions of Space*, pp. 47–56; and Defense Intelligence Agency

(DIA), *Soviet Military Space Doctrine,* DDB–1400–16–84 (Washington, DC: Defense Intelligence Agency, 1 August 1984).

18. DIA, *Soviet Military Space Doctrine,* p. 11.

19. Deudney, "Unlocking Space," p. 101.

20. US Department of Defense, *Report to the Congress on ASAT Arms Control* (Washington, DC: U.S. Department of Defense, 31 March 1984), p. 6.

21. See Colin S. Gray, *American Military Space Policy: Information Systems, Weapon Systems, and Arms Control* (Cambridge, MA: Abt Books, 1983), pp. 45–6.

22. DIA, *Soviet Military Space Doctrine, p. 31.*

23. See Robert B. Giffen, *US Space System Survivability: Strategic Alternatives for the 1990s,* Monograph Series No. 82–4 (Washington, DC: National Defense University Press, 1982).

24. The Soviet NAVSTAR GPS.

25. See Wolfgang K.H. Panofsky, "The Mutual Hostage Relationship Between America and Russia," *Foreign Affairs,* Vol. 52, No. 1 (October 1973), pp. 109–18.

26. An outstandingly lucid critique of recent trends in US strategic policy is Robert Jervis, *The Illogic of American Nuclear Strategy* (Ithaca, NY: Cornell University Press, 1984), particularly Chapter 2.

27. See Colin S. Gray, "War-fighting for Deterrence," *The Journal of Strategic Studies,* Vol. 7, No. 1 (March 1984), pp. 5–28.

28. "President's Speech on Military Spending and a New Defense," *The New York Times,* 24 March 1984, p. 20.

29. US Arms Control and Disarmament Agency, *Arms Control and Disarmament Agreements: Texts and Histories of Negotiations* (Washington, DC: US Government Printing Office, 1982), p. 139.

30. *US Arms Control p. 140.*

31. For a careful analysis of this subject, see *The SDI and Future US-Soviet Arms Control Strategies and Implications* (Fairfax, VA: National Institute for Public Policy, 1984). Also see Christopher Paine, "The ABM treaty: looking for loopholes," *Bulletin of the Atomic Scientists,* Vol. 39, No. 7 (August/September 1983), pp. 13–16.

32. For analysis of the idea of a "defensive transition," see Keith B. Payne and Colin S. Gray, "Nuclear Policy and the Defensive Transition," *Foreign Affairs,* Vol. 62, No. 4 (Spring 1984), pp. 820–42.

OPTIONS FOR SPACE ARMS CONTROL

Alex Gliksman

This paper reviews the key problems associated with space arms control and identifies several arms control options. Antisatellite (ASAT) weapons and advanced strategic defense systems are considered, with particular emphasis on the former.

Although there is widespread agreement that American security interests would be well served by agreements creating a benign environment for space operations, there is broad divergence on whether militarily useful accords can be reached. At the base of these differences are four principal areas of concern:

1. Verification and the associated problem of defining what is and is not a weapon;

2. The status of space-based gun sights, such as the Soviets' ELINT and RORSAT surveillance systems, which, although not weapons in and of themselves, are viewed as components of weaponry;

3. The relationship between constraints on current space capabilities and future strategic defenses; and

4. The role of arms control in advanced strategic defense activities.

GENERAL OBSERVATIONS ON VERIFICATION

Verification requirements for space accords will be stringent, particularly for agreements involving bans or other significant restraints on ASAT capabilities. The key issue here is US dependence on a relatively small number of satellites for military operations. Military satellites are, therefore, high-value targets. The military consequence of an attack by a few clandestinely stored or manufactured ASAT's may provide great incentive for breaching an arms control accord. The risks and the incentives of violation make gaps in monitoring capabilities intolerable.

An analogy with nuclear arms control makes this point most clearly. Suppose an agreement is reached to reduce strategic forces by 20 percent below current levels on each side. A violation in which tens of weapons were retained in contravention of the accord would not seriously affect the strategic balance. If, however, arms reductions led to massive cuts and no more than 100 weapons were permitted on each side, the failure to monitor the breach of tens of weapons would assume unacceptable proportions. Given the small number of satellites, the verification requirements for ASAT arms control approach the second condition more closely than the first.

Clearly, realism dictates caution, but there is still room for accord on ASATs. There may, however, be a need for rigorous verification procedures to ensure compliance, and these will probably involve measures requiring active cooperation by the Soviet Union. Soviet willingness to bend on the issue of intrusiveness may also be necessary. Although nothing definitive can be said about Moscow's attitude prior to negotiations, a statement last June by Soviet leader Konstantin Chernenko, opened the door to "other forms" of verification, beyond national technical means.

ELIMINATING DEDICATED ASATs AND THE RESIDUAL THREAT

ASAT arms control skeptics do not believe that effective bans or restraints can be achieved. They believe there are simply too many ways to defeat an agreement through so-called residual capabilities. They have focused on the ASAT potential of untested and jury-rigged ASATs and attach great significance to clandestinely retained or manufactured dedicated ASAT systems and to the ASAT potential of embedded weapons systems that are either deployed intercontinental ballistic missiles, (ICBMs) or antiballistic missiles (ABMs) or under development (notably, high-powered lasers).

These skeptics have offered several deadly scenarios. For instance, satellites designed for other purposes are loaded with explosives. After launch, they are maneuvered next to a target and detonated, destroying themselves and their targets. Alternatively, after Moscow agrees to destroy its ASAT, together with the associated SL-11 launchers, the Soviets hide or manufacture some ASAT interceptors. They can get away with this because the United States does not know the size of the interceptor inventory and, even if it did know the Soviets could build copies without the United States finding out. When required, the Soviets would load the illegal payload atop another booster and fire it for attack against US space assets.

Contravention via the first scenario would befit a 21st-century Quaddafi, not a superpower like the Soviet Union. A jury-rigged or unproven ASAT is at best a tool of blackmail or terror: it is not a weapon of grand strategy. The Soviets are prudent defense planners, and they have a far more conservative weapons design philosophy than the United States has. The Soviets tend to stick to proven concepts; their new weapons systems differ only marginally from their older ones. It is the United States that places a premium on innovation and technological risk taking.

A militarily significant attack designed to degrade US space capabilities would in most cases involve well-coordinated strikes against a relatively large proportion of US space-based assets. This requires confidence in the reliability of ASAT systems. Makeshift weapons cannot assure success. The Soviets are unlikely to put much faith in an attack by improvised means and are unlikely to divert resources to such a purpose. But even if they decided to gamble, this form of attack is likely to succeed only if arms control arrangements are treated as a substitute for survivability enhancements. More will be said on this later.

The consequences of the second scenario are not very different from those of the first. After destruction of SL-11 launch facilities, the Soviets would have to attach their ASAT interceptor to a different booster. The uncertainties of launching a proven interceptor on a new booster are nearly as great as those involved in operating a totally untested system. The characteristics of each booster type are unique. Each has a distinct flight profile, including such things as rattle, that affects payload performance and delivery.

Rules for counting multiple independently targetable reentry vehicles (MIRVs) developed during the SALT negotiations credit each booster with carrying the maximum number of warheads with which it has been tested. This standard reflects a conclusion that to deploy warheads above tested levels would cause unacceptable uncertainties in system reliability. Therefore, this form of noncompliance was judged not to be militarily significant. Nevertheless, specialists believe that a marginally augmented but untested MIRV payload is more reliable than an ASAT interceptor launched on a new booster, because the first case involves incremental adjustment; whereas the second case involves a totally new configuration.

Thus, even with a higher standard for ASAT verification, we can have equal, if not greater, confidence in a dedicated ASAT ban, requiring destruction of a small number of ASAT launch sites. Destruction of the launch site is the key element in such a prohibition. Without proven launch facilities, clandestinely stored or manufactured interceptors and boosters would be of little value for quick breakout in crisis or war.

The difficulty of improvisation is made eminently clear by the dismal test record of the Soviet's dedicated ASAT system. Approximately half of the 20 attempts against cooperative targets have been judged failures. Attacking satellites in orbit is a complex task for a conventionally armed ASAT.

DEALING WITH EMBEDDED SYSTEMS

This assessment does not eliminate the worry voiced by arms control skeptics about the ASAT potential of the Soviets' embedded systems. If the Soviets cannot depend on the reliability of improvised ASAT weapons, they could still employ some or all of their 100 nuclear-tipped GALOSH ABM interceptors around Moscow or part of the ICBM force, such as the SS-18. But, at present neither capability is a reliable satellite killer. First, nuclear detonations in space have a large kill radius, and would endanger Soviet satellites in the vicinity as well as the intended target. The United States maintained a nuclear-tipped ASAT system until 1975, when the imprecision of this kill mechanism reportedly led to its abandonment. Second, a nuclear attack on satellites in low orbit over the Soviet Union might disrupt ground communications and electronic equipment over a wide area. Third, in a nuclear war scenario, employing GALOSH ABM interceptors for satellite strikes would reduce the number available to engage incoming warheads.

It is in the interest of the United States to assure that the ASAT potential of these embedded systems is not transformed into ASAT capabilities. Such a transformation could occur in the absence of constraints on testing ballistic missiles or ABM interceptors in a "straight-up" ASAT mode. Improvements in accuracy would follow sufficient testing. High accuracy would permit the use of a conventional warhead, avoiding the liabilities of nuclear detonations in space.

The Soviet Union's high-powered laser facilities, such as the one recently identified at Sary Shagan, is another embedded system with ASAT potential. It is unclear whether such a system can disable satellites, but even if it has such a capability, there are a number of practical limitations. Current high-energy lasers have to be pointed straight up (the shortest possible distance through the atmosphere); atmospheric effects also impair accuracy and cloud cover can put a laser out of business for weeks at a time. Using the deadliest assumptions, the Soviets must wait until the target is directly overhead and hope for clear day.

Like jury-rigged systems, the potential ASAT capability of the laser facilities is not militarily significant. Attacking a large portion of the US satellite network would, among other things, require a large number of highly dispersed lasers throughout the Soviet Union.

High-powered lasers are detectable and laser tests against space objects are, reportedly, observable with appropriate sensors. A ban on large lasers may be a technically feasible approach to this ASAT problem, but, given the US interest in research on directed-energy ballistic missile defense (BMD), the United States may view any ban on large lasers as unacceptable. A more limited approach might seek to restrict the number, locations, and power of lasers. For instance, one element of such an approach might restrict laser facilities to the two sites permitted under the ABM Treaty. This could prevent acquisition of significant ASAT capabilities.

THE IMPORTANCE OF SURVIVABILITY ENHANCEMENTS

Measures to enhance survivability are a critical complement to any space arms control regime. What constitutes a militarily significant threat varies with the size of a satellite constellation assigned a particular mission. Potential vulnerabilities would be reduced if the United States were to provide a redundancy. Stocking rapidly deployable replacements together with quick-response launch vehicles is one approach. Peacetime deployment of on-orbit spares is another. A third might involve a shift away from reliance on a few, difficult to replace, multimission space systems toward proliferation of many single-role satellites.

The uncertainties of relying on unproven or makeshift ASAT systems coupled with survivability enhancements reduce the potential reward of ASAT breakout, so increasing incentives for compliance.

A variety of lesser ASAT threats have also been identified, such as spoofing, jamming, and attacking with low-powered lasers. In view of the fact that these types of capabilities are widely available or are inherent in systems designed for other purposes, these lesser ASAT threats could pose a verification nightmare. Fortunately, survivability enhancements can effectively neutralize these threats. Problems can be solved by unilateral action rather than through arms control. Shielding against low-powered lasers is readily available. Satellites can be hardened, computer capabilities can be increased to provide autonomy, and electronic measures can be incorporated to counter a wide range of other threats. These and other components of a survivability regime are already being built into the US space systems, though more needs to be done.

Survivability measures are most potent against threats at the margin. They offer little protection against a determined adversary armed with well-honed instruments of destruction. Well-devised negotiated restraints are the one effective counter to the deadliest threats. In this sense, the utility of unilateral protective measures may depend on arms control—and vice versa.

SPACE-BASED GUN SIGHTS

The Soviet Union's deployment of space-based systems that provide targeting information on US and allied forces, especially navies, is of concern to defense planners. Indeed, the defeat of Soviet radar ocean reconnaissance satellite (RORSAT) and electronic intelligence (ELINT) surveillance systems is a principal rationale for US ASAT deployment.

Some analysts have chosen to downplay this threat, saying that the Soviets have other means for acquiring this information. Soviet undersea and surface forces can shadow and report on naval forces, and they can directly attack naval units without coordination with other force elements. Moreover, US Navy officers have assured Congress that the F-15-launched ASAT is unnecessary for RORSAT suppression. The Navy reportedly possesses other means (presumably electronic countermeasures and decoys) to defeat the space-based surveillance threat.

Nevertheless, space deployment of emerging targeting technologies raises broader questions about whether this category of space system should benefit from the protection of an ASAT accord. If today's RORSAT threat is judged to be a manageable problem, not requiring negotiated constraints, the risks inherent in future technology may demand prohibitions on space-based gun sights, even though they are not weapons in and of themselves.

The potential dangers are highlighted by press reports of Soviet efforts to develop space-based submarine-tracking capabilities. Should such systems ever be perfected and deployed, the end of strategic missile-carrying submarine invulnerability would be at hand. The ensuing situation would be extremely destabilizing.

For precedent-setting purposes, some specialists may argue that in dealing with the gun-sight problem the time to start is now, with RORSAT and ELINT. Such provisions would be easiest to verify if all gun sights were prohibited. This would avoid future disputes over permitted versus prohibited qualitative improvements. Since the Soviet ASAT and the RORSAT and ELINT systems share the same launchers, it would be easiest to negotiate a gun-sight prohibition if it were coupled with an ASAT ban, requiring dismantlement of SL-11 launchers. If the ban were to cover the ASAT alone, the Soviets could shift RORSAT and ELINT payloads to a new launcher.

OTHER APPROACHES: TESTING CONSTRAINTS, "GRANDFATHERING" ARRANGEMENTS, AND CONFIDENCE-BUILDING MEASURES

Although specialists generally agree that the US ASAT in development will be more capable than the Soviet SL-11 co-orbital system, many experts believe that both systems represent relatively crude capabilities when compared with systems that may be available in the future. Several arms control proposals reflect the view that if elimination of current ASATs proves difficult to negotiate, the next step should be the creation of barriers to further development.

Several different ASAT test bans are among these options. The most restrictive approach would ban all flight tests immediately. Because ASAT tests have observable signatures, a test ban would be easily verifiable. Unfortunately, this is a quick fix rather than a durable approach. It would leave the Soviets with the world's only operational ASAT. Although advocates claim that the inability to test would degrade Soviet confidence in the SL-11 system, cautious US defense planners must continue to assume the SL-11 would successfully intercept satellites in low orbit about half the time. For some US space networks with only a few satellites performing a mission, a 50 percent success rate may be unacceptable. Skeptics might view a testing accord as little more than a no-first-use agreement. It may work perfectly well in peacetime, but during conflict it would quickly come undone.

Test ban advocates claim that this quick fix is only a first step in stabilizing the situation while talks on additional restrictions proceed. But despite lack of progress at the bargaining table an open-ended ban could become permanent. It's quite likely that the Soviets favor space talks because they are worried about US ASAT development. Indefinitely suspending US ASAT tests could remove the very incentive required for Soviet concessions on verification and other arms control issues.

A moratorium planned to terminate on a certain date is an alternative. This would maintain pressure on Moscow to negotiate seriously. If a dedicated ASAT ban was the ultimate goal of space talks, a limited moratorium would defer plans to perfect the US ASAT and thus avoid the tricky verification problems associated with this small and mobile system. But clearly any moratorium should be imposed only after talks establish elimination of dedicated ASAT systems as a goal.

A prohibition against high-altitude tests might be associated with efforts to produce a "grandfathering" agreement, under which the Soviets would retain their SL-11-launched ASAT and the United States would be permitted to make the F-15-launched system operational. A halt to development of more advanced ASATs that are capable of striking at space systems at high altitudes or employing different kill mechanisms is the major merit of a "grandfather" accord.

In speaking to Western visitors, the Soviets have expressed interest in such an accord, but their definition of this concept seems to differ from ours. The Soviets idea could be better described as "grandfather plus one"; they seem to hold the view that the US ASAT will be so superior that a grandfather agreement should allow them to develop and deploy a system with capabilities comparable to those of the F-15 ASAT. This would leave the Soviets with experience in developing two proven systems while the United States would have experience with only one. More important still, this type of grandfather agreement would require the United States to stand still while Moscow could proceed with developing a follow-on to the SL-11 system. Thus a treaty based on grandfather plus one is a nonstarter. A US standstill would require a level of trust in Soviet commitments that does not now exist. Such a treaty would face significant opposition in the Senate. Sentiment in favor of US rights of equity in weapons development, reflected in the Jackson amendment to SALT I, continue to run strong.

A space arms control workshop conducted recently by the Congressional Office of Technology Assessment (OTA) concluded, "Future US and U.S.S.R. activities in space hold great potential for generating uncertainty and misunderstanding regarding the countries' respective intentions." Given the trend toward increased use of space by both sides, ambiguities associated with even benign activities could create risks of misperception and overreaction. Confidence-building measures including exchange of plans, program data, and visits by personnel could be invaluable in avoiding tensions.

Agreement on various rules of the road, such as sanctuaries around satellites or limitations on speed of approach for rendezvous, also could help build confidence. Trespass into sanctuaries by the other country's satellites would be a warning indicator, and restrictions on rendezvous procedures might hinder the use of ostensibly "peaceful" activities to practice interception and attack.

Rules of the road by themselves would be little more than the lowest common denominator of arms control. They would have minimal value if dedicated and embedded ASAT systems were uncontrolled. This is particularly true for laser weapons, for which sanctuaries and rendezvous restrictions would pose no obstacle to attack.

CURRENT RESTRAINTS AND FUTURE DEFENSES

Restraints on ASATs and on space-based gun sights may conflict with the goals of the Strategic Defense Initiative (SDI). In many respects it is much harder to destroy a missile in flight trajectory than it is to destroy a satellite. A good space-based or space-directed BMD system is also an excellent ASAT, but the converse is not true.

A dedicated ASAT ban would reinforce the existing injunctions contained in the ABM Treaty prohibiting all missile defenses except for 100 interceptors located at one site. Prohibiting gun sights would block development and deployment of sophisticated space-based sensors for defense against submarine-launched ballistic missiles.

THE ABM TREATY AND THE STRATEGIC DEFENSE INITIATIVE

The 1972 ABM Treaty permits both the United States and the Soviet Union to deploy BMD systems at two sites, each equipped with no more than 100 interceptors. A 1974 protocol reduced the number of permitted sites to one. The treaty further prohibits efforts "to develop, test, or deploy ABM systems or components which are sea-based, air-based, space-based, or mobile land-based."

Research and preliminary development work on all types of BMD systems is permitted. Advanced development is prohibited. The boundary between what is permitted and what is banned was described by our negotiator of the ABM Treaty, Gerard C. Smith, on 18 June 1972, in testimony before the Senate Armed Services Committee:

> The prohibitions on development contained in the ABM Treaty would start at that part of the development process where field testing is initiated on either a prototype or breadboard model. It was understood by both sides that the prohibition on "development" applies to activities involved after a component moves from the laboratory development and testing stage to the field testing stage, wherever performed. The fact that early

> stages of the development process, such as laboratory testing, would pose problems for verification by national technical means is an important consideration in reaching this definition.

This boundary is clear-cut. In the words of one participant in the OTA space arms control workshop: "If I see one outside the laboratory—a prototype, a breadboard model—if I see one, it's a violation."

Active research is implicitly encouraged by the ABM Treaty regime. This provides a prudent hedge against Soviet breakout and it creates incentives for continued treaty adherence. The ABM Treaty research regime seeks to create a stable equilibrium for continued adherence to the accord rather than to encourage a race toward breakout. Research that keeps pace with Soviet activities is consistent with this regime.

SDI advocates present three arguments in favor of the program. First, SDI is a necessary response to Soviet BMD activities. Second, as a research program, the SDI is permitted under the ABM Treaty. Third, this research may provide means to render nuclear weapons ineffective. This promotes the true objective of arms control.

With regard to the first assertion, there is ample testimony to support the view that the BMD research efforts in the United States before SDI were sufficient to keep pace with the efforts of the Soviet Union. On 23 March 1983, just hours before the President proposed the SDI, Defense Advanced Research Projects Agency Director Robert Cooper told the House Appropriations Committee that the United States was pursuing space-laser "technology ... at a rate which will certainly make it impossible for the Soviets to breakout with a capability that we could not either duplicate or counter." In November 1983, the Senate Foreign Relations Committee released a report stating, "Absent evidence to the contrary, [BMD research] proposals reportedly under consideration ... appear to go well beyond the level of effort required in guarding against" breakout. Testimony by OTA before the same committee on 25 April 1984, is more emphatic on this point: "Before the SDI began, the United

States had an extensive program of BMD research ... ensuring that our technology was keeping pace or staying ahead of" the Soviet Union.

Although SDI is a research effort permitted under the treaty, questions have been raised about the merits of a program whose objective is not merely a hedge against breakout but a decision on full-scale development. The SDI could propel Soviet BMD activities and potentially put the Soviets in position to break out of the accord, even if the United States decides to forgo advanced development and deployment. And again, should the United States conclude that continued adherence to the ABM Treaty is the better option, this situation could ultimately force the United States to proceed with BMD acquisition.

Although few people quibble with the desirability of systems that could reduce the risks of nuclear devastation, the path from here to there is littered with uncertainty. The risks are particularly grave if actions result in the abandonment of the ABM Treaty regime before doubts are resolved on the technical and strategic merits of futuristic BMD. In the words of the President's Commission on Strategic Forces, the Scowcroft Commission,

> Research permitted by the ABM treaty is important in order to ascertain the realistic possibilities which technology might offer, as well as to guard against the possibility of an ABM breakout by the other side. But the strategic implications of ballistic missile defense and the criticality of the ABM treaty to further arms control agreements dictate extreme caution in proceeding to engineering development....

ARMS CONTROL AND STRATEGIC DEFENSE DEPLOYMENT

Strategic defense deployments and arms control efforts are widely believed to be inexorably linked. The process of developing arms control arrangements associated with strategic defenses must run parallel with, if not precede, the technology program.

President Reagan addressed a major strategic risk in stating, "If paired with offensive forces, they [defensive systems] can be viewed as fostering an aggressive policy." According to the President's advisers on defensive technology, the so-called Fletcher Commission, there are important technical reasons for arms control. According to the Fletcher Commission, effectively sizing a defensive deployment requires an agreement constraining Soviet strategic offensive forces.

Both positions support the conclusion that agreements on nuclear arms reductions should precede deployments. Unfortunately, experience suggests that a Soviet Union faced with the prospect of US defensive deployments would seek to augment rather than to reduce offensive capabilities. Even the meager offensive limitations in place today could vanish.

Much depends on whether science fulfills the promise that emerging technologies will reverse the cost ratio that currently favors the offense over the defense. Unless this hope is realized, reductions in offensive arms may be incompatible with strategic defense.

In 1972, US concerns about Soviet offensive systems and Soviet concerns about an American ABM buildup were linked in an exchange. Soviet concerns were met by the ABM Treaty and American concerns were met by SALT I's offensive limitations. Today, we are in a similar situation. The United States is again worried about Moscow's missile force. Thus far, the Soviets have resisted the deep reductions that the United States wants. At the same time, there is no doubt that the Reagan administration is committed to the SDI and that the Soviets claim to be alarmed by this program. The SDI could be the leverage needed to move the Soviet Union toward the level of reductions they have previously avoided. Former Defense Secretary James Schlesinger believes conditions may be right for another exchange.

After a first START agreement is achieved, we could pursue further reductions and conduct, at a deliberate pace, research towards a better defense. If drastic reductions are eventually produced, strategic defenses may become indispensable. The verification problems associated with drastic reductions to, say, 100 nuclear weapons on each side, are serious. Under those conditions, strategic defenses would be a vital insurance policy against violations.

SPACE ARMS CONTROL

Henry F. Cooper

WAS ANDROPOV MARRIED?

About a year ago, my neighbor, Senator Rudy Boschwitz, asked me to review a White Paper he had prepared on nuclear arms control. It was a good paper, but one detail bothered me. To illustrate differences between our open society and the closed Soviet society, the Senator had noted that we did not even know whether General Secretary Andropov was married, while everyone knows details of Nancy Reagan's interests and activities. This contrast made his point effectively, in simple, understandable terms.

But I could not believe that we did not know whether Mr. Andropov was married. I called one of the nation's experts on Soviet military and political matters, who told me that Mr. Andropov was a widower but that he had remarried. I then told Senator Boschwitz he should not use his example, thinking this fact was probably common knowledge in the intelligence community. Some months later Mr. Andropov died. On that day, the newspapers indicated that he was a widower and was not married. The next day the newspapers ran photographs of Mrs. Andropov seated next to her husband's coffin. In the final analysis, the Senator had been right.

The point of this story is that in the United States we are used to a free flow of information, the benefits of a free press, an open political process, and easy access to substantive information on foreign policy matters. We tend to assume others share our experiences. Unfortunately, this American way is imprudent when dealing with the Soviets on any matter of substance. The difference between our open and their closed societies—and between our two forms of government—have profound implications for our arms control and defense policies.

Our national security policies and programs result from open debate and political competition guided by our constitutional process. Our policies and programs evolve "in a fishbowl." Our policymakers are responsive to many political pressures Soviet rulers can simply disregard in formulating their policies and programs. Furthermore, the Soviets have many opportunities to manipulate the pressures on our political process, and their propaganda and disinformation programs often are targeted accordingly to encourage us to accept adverse negotiating positions. Space arms control is such a case.

Returning to Senator Boschwitz's point, the *Congressional Record* and other publications of our free society provide much information about our defense programs, the level of support and projections of future weapons systems. This information (which is readily available to the Soviets), plus the information they can gain from relatively free access to most of our country, enables them to evaluate our defense programs and our compliance with treaties we sign. We have to pay dearly to estimate their capabilities, their research programs, and their likely future developments—facts our open society provides them for the taking. National Technical Means constitute our primary source of verification data—and these methods are becoming less and less adequate with time. Technology is constantly developing, as in the area of mobile missiles.

Our concerns about verification are augmented by evidence of Soviet noncompliance with a number of agreements they have signed. Perhaps of greatest concern with respect to this conference on space and strategic defenses is the construction of the Krasnoyarsk radar, almost certainly in violation of the 1972 ABM Treaty. The Soviets probably decided to build this radar—which they knew we would see and recognize as inconsistent with the ABM Treaty—in the 1970s, perhaps while SALT II was being completed.

Such events emphasize that we must be able to verify independently Soviet compliance with any agreement we make with them. Otherwise we unilaterally accept constraints while imposing none on the Soviets. Furthermore, we must maintain safeguard programs to assure that they gain no significant advantage by cheating or breaking out from any agreement they sign with us. This is especially true for space.

US SPACE ARMS CONTROL POLICY

US policy on space arms control was set by President Reagan on 4 July 1982. He said:

> The United States will continue to study space arms control options. The United States will consider verifiable and equitable arms control measures that would ban or otherwise limit testing and deployment of specific weapons systems, should those measures be compatible with United States national security.

These three criteria, that an agreement be equitable, verifiable, and compatible with US security are simple but stringent. We wrestled with them, within the bureaucracy, for some time and then on 31 March 1984, the President provided Congress with the results of our studies in his report on US policy on ASAT arms control. I will not try to summarize that report here. The president's report must be read carefully by everyone who has a serious interest in space arms control. For this paper it will suffice to reiterate a few important points.

First, hostile satellites exist. There are present and projected Soviet space systems which, while not weapons themselves, are designed to support directly the Soviets' terrestrial forces in the event of a conflict. These include ocean reconnaissance satellites that use radar and electronic intelligence to provide targeting data to Soviet weapon platforms, which can then quickly attack US and allied surface fleets. As Soviet military space technology improves, the capabilities of Soviet satellites that can be used for targeting are likely to be enhanced and represent a greater threat to US and allied security. We cannot permit such threatening capabilities to have sanctuary in space any more than reconnaissance aircraft were permitted sanctuary in World Wars I and II.

Second, there are many ways to attack satellites, and a number already exist in the Soviet Union. For more than a dozen years, the Soviets have had an operational antisatellite system (ASAT) that threatens low-altitude satellites of the United States and other nations. They have two ground-based lasers we judge to be capable of damaging satellites, and we believe they are conducting research and development (R&D) in the area of space-based laser ASAT systems. The Soviets also could probably attack satellites with the nuclear-armed ABM interceptors of their Moscow [illegible] system. They could modify ICBMs for nuclear attacks on s[illegible]tes. They could use electronic countermeasures against s[illegible]s. They could, in the future, develop nonnuclear, exoatm[illegible] ABM interceptors that would have the capability to att[illegible] satellites. And, finally, they could use a spacecraft with sufficient maneuvering capabilities and weight capacity to detonate explosives next to another nation's satellite.

Third, verification of Soviet compliance with an ASAT agreement would be very difficult. As we have already noted there are many kinds of ASATs. The growing variety and complexity of normal, non-ASAT, operations in space provide a number of possible scenarios for cheating. The Soviets could, for example, exercise various elements of ASAT interceptor testing under cover of docking operations. More generally, verification of arms control agreements suffers from the extremely asymmetric degree of openness between the United States and the Soviet Union already discussed. The open US society makes the Soviet task of monitoring US arms control compliance relatively easy. In contrast, the closed Soviet society and the general Soviet tendency toward secrecy make US monitoring and verification of compliance much more difficult. This problem is aggravated for ASAT systems because there are only a few satellites that serve US and allied security. Cheating on antisatellite limitations, even on a small scale, could pose a disproportionate risk to the United States.

For these and other reasons, the president's report concluded, in essence, that a comprehensive ban on all means of countering satellites would be neither verifiable nor in our interest. But the report noted that the search for viable arms control opportunities in the ASAT area was continuing and that there was a premium on finding ways to limit those ASAT systems that create the most difficult survivability problems. The door is not closed, therefore, to equitable, verifiable measures compatible with US security.

Congress implicitly accepted this conclusion when the language was changed from that of the FY 1984 Defense Authorization Act. This required presidential certification, according to the Tsongas Amendment, of endeavoring in good faith to negotiate a comprehensive ban on ASATs before proceeding with MV testing against an object in space. The FY 1985 Act requires the president's willingness to negotiate only the "strictest possible limitations."

CURRENT STATUS

Following submission to Congress of the 31 March report on ASAT arms control, the administration conducted a further intensive study of specific space arms control options. Although it is not appropriate to review those studies here, some personal impressions may be instructive.

A major lesson is that ASAT technology and ABM technology overlap. Any exoatmospheric ABM could be configured for use as an ASAT. For example, in the Homing Overlay Experiment, the intercept of the ballistic missile interceptor with a reentry vehicle at an altitude exceeding 100 miles, could just as well have been with a satellite. Thus, if ABM R&D permitted by the ABM Treaty is to be allowed to continue, it is impossible to preclude development of low-altitude ASAT capabilities. Furthermore it is very hard to find consequential or substantive ASAT arms control limitations that are verifiable and do not affect the research on ABM systems under the Strategic Defense Initiative (SDI). Our position on ASAT arms control should not prejudge, one way or the other, the results of that research; neither should it prevent the necessary research.

The reality is that there is no way to stop the increasing potential for space weapons. The issue is how to manage the march of technology and our competition with the Soviet Union to best enhance US security and strategic stability. Arms control can help, as a complement to necessary defense activities involving space. There will be two debates on these issues over the coming months. The public one will be paced by the US congressional budget process. It will have to do with the need for and place of SDI research; the scope of continuing strategic modernization of our intercontinental ballistic missiles ICBMs, submarine-launched ballistic missiles (SLBMs, bombers, and cruise missiles; policy issues including those regarding Soviet noncompliance with existing agreements and our policy of "no undercut" of SALT I and II during negotiations on new agreements; and the US position on strategic, intermediate-range, and space weapons in such negotiations. A multidimensional debate of such broad scope is bound to be extraordinarily complex, and its intensity will be exacerbated by a backdrop of a perceived budgetary crisis associated with the deficit. The Soviets will have full access to virtually all important aspects of the debate and they can be expected to attempt to influence the outcome by public diplomacy and negotiating strategy.

The debate will also have considerable allied participation. Our allies have individual concerns. The French and British, for example, will evaluate possible effects of any changes in the nature of the strategic balance on the viability of their national nuclear deterrent forces. Our allies have, in addition, a common general concern: to maximize the effectiveness of deterrence in order to minimize the likelihood of war. Our government will need to show allied governments the ways in which SDI may affect both kinds of concerns. Allied leaders have been making, and will no doubt continue to make, public statements on SDI; those statements and the statements of their opposition parties will be used (on all sides) in the US debate.

The second debate is not entirely disconnected from the first but will take place at the negotiating table between the United States and the Soviets. It will involve offensive and defensive nuclear weapons, space, and possibly other issues. We are unlikely to have access to any internal Soviet discussions leading to their positions at the negotiating table, but the Soviets will have the luxury of adjusting their positions to make maximum use of the pressures of the internal US debate.

The Soviets, for example, continue to frame the discussion on space weapons on an oversimplified, emotional level in terms of preventing the "militarization of space", or avoiding enlarging the arms race into the heavens. Such a goal is nonsense. Ballistic missile tests, tests of interceptors of ballistic missiles, and the activities of a wide variety of military support satellites are, and have been, regular features of outer space for decades for both the United States and the Soviet Union. All these activities cannot be halted by any realistic agreement; space can not be "demilitarized." Rather, specific, limited agreements may be able to help ensure that space activities are conducted in ways that decrease the chances of war.

A major Soviet goal is clearly to stop the SDI program. Provisions of the draft space treaty they tabled at the United Nations in the summer of 1983 would effectively impede the SDI research program. It is easy to understand their motivation. They respect our ability to develop and employ new technologies once we set our minds to it. And they are concerned that research conducted in this program has the potential to undercut their very large investment in offensive ballistic missiles by significantly reducing their effectiveness.

The Soviets understand the importance of defenses perhaps better than we do. They have consistently, outspent us on strategic defenses by perhaps 10 to 1. They maintain the world's only operational ABM system—around Moscow—and are upgrading that system. They maintain extensive air defenses and have for many years had a major civil defense program. They do extensive R&D on "conventional ABM" and they have large R&D programs on directed-energy weapons. In some areas they may be ahead of us. In fact, we could perhaps more accurately have called our research program SDR—the Strategic Defense Response—instead of SDI.

PROSPECTS

If the Soviets are prepared for serious talks, they will find us ready. The United States has indicated the priority it attaches to reductions in offensive nuclear weapons, both strategic and intermediate range. We have also indicated that we will be flexible in addressing this subject, and in discussing trade-offs between areas of US advantage and areas of Soviet advantage. And we have stated that we are prepared to negotiate agreements on space arms. At the same time, we are not interested in unrealistic arms control that would preclude the research necessary to evaluate the actual potential of new technologies for strategic defense. The United States has also attempted to keep the exchanges in diplomatic channels, rather than airing them in public, in order to facilitate a more frank and productive exchange. It is to be hoped that the Soviets will adopt a similar posture. The United States is prepared for detailed, substantive exchanges on offensive weapons, space, and defenses. The driving factor in assessing the likelihood of agreement between the United States and the Soviet Union is the extent to which the Soviets are prepared for serious exchanges.

With respect to the upcoming congressional debate, I want to close with a bad news/good news story. First the bad news. I recently attended a meeting with friends of the SDI program from within the government and from industry. In the best American tradition, they were making research and testing plans to help realize the president's vision to develop effective defensive systems. Unfortunately, they were not familiar with all the restraints the ABM Treaty places on various R&D efforts, particularly testing. And so some of their embryonic plans were inconsistent with the treaty and are not therefore those of the administration. Because the administration's policy is that the SDI program will be consistent with the ABM Treaty, the meeting suggests that our best friends may cause us trouble in their well-intentioned advocacy of the President's program. But let there be no doubt! Our SDI program will be consistent with the Treaty; we will make it so.

Finally, the good news. I also recently attended a meeting with a group hostile to the SDI program, a group that will provide many arguments to our opposition in the upcoming congressional hearings. Yet, I found much common ground. We agreed on the following points:

The phrase "the militarization of space" is rhetorical nonsense, because space has long been militarized, and such rhetoric is not helpful to conducting an informed debate.

We cannot permit a blanket sanctuary to hostile satellites—satellites that threaten stability in conventional conflicts and, more important, under conditions that could escalate to nuclear war (that is, there is a valid requirement to counter threatening satellites).

Any exoatmospheric ABM will make a superb antisatellite weapon. Therefore, ASAT restrictions without ABM restrictions beyond those in the ABM Treaty will have marginal utility in restraining the development of ASAT capabilities.

Research on strategic defenses is necessary as a hedge against Soviet breakthrough in their research programs.

At least some defenses can, in principle, improve stability if they are cost-effective in the sense that offensive countermoves are much more expensive. Clear examples are those that enhance the survivability of our strategic retaliatory capability.

Although there is disagreement on many issues—some might even be better characterized as misunderstandings of the President's vision and our evolving program—the good news is that there is much common ground and reason for hope that the upcoming congressional debate can be informed and constructive.

NEW OBJECTIVES

Hans Mark

Professor Rostow has advertised that I will give a benediction. If you look at the origin of that word, it means to say something good. I hope I can do that. Perhaps the best way for me to close this meeting on the subject of "America Plans for Space" is to do it in the style of a good news and bad news story. Perhaps it isn't good news and bad news: I don't think any of the news we heard here was bad. Let me say it is good news and the real world.

The good news I find from this meeting is that there is remarkable agreement on the status of space technology and what our capabilities really are. Let me list a few points and discuss them briefly.

We start with science and the quest for knowledge as one of the major reasons we go into space. Yesterday Charlie Pellerin talked about the space telescope, which will surely be the most remarkable scientific instrument that we have ever flown and may be the focus of the most remarkable scientific experiment that we have ever done. With that instrument we will, for the first time, be able to look out to the edge of the universe, the edge of what started with the so-called big bang 15 billion years ago. I cannot predict what will come from using the telescope except to say that clearly it will be a step toward a new frontier in human experience.

Equally important, when someone asked what the first priority would be in the observational program of the space telescope, the answer was, to look for planets around other stars. I leave it to your imagination to figure out where that might lead, because where there are planets there are plants, and where there are plants, there are animals, and where there are animals there might be intelligence—human intelligence. In any event, I find the prospect of the space telescope and things like it to be enormously exciting. As long as that is in our plan for space, I think that is enormously good news.

Let me also talk about the space shuttle and launch vehicles. It is amazing that in 3 short years we are now taking the space shuttle for granted. In late 1978, there was a proposal to cut back the space shuttle program to a research and development program. Harold Brown persuaded President Carter, in my presence, to keep what is now a major national success story going. That is good news. I think the whole launch vehicle question also is going to be resolved favorably in the sense that we are going to explore the proper technologies. We will have not only the shuttle as a launch vehicle but a stable of things that will meet our requirements.

Our civil space program has a major new objective. President Reagan's commitment to the space station was an important forward step in a series of steps that have characterized our civil space program. I had the great fortune of being involved in that debate and I think this is an important new direction. Let me repeat the four reasons we should build a permanently manned space station, reasons that were first compiled by a group chaired some years ago by Jim Fletcher:

First, the space station is a maintenance base, to be used to maintain, repair, and refurbish satellites in the future. We have already refurbished one satellite. Last April we picked up a satellite from orbit, repaired it on the shuttle, and redeployed it. Just last month we picked up failed satellites, brought them back, and are going to fix them to fly again. This kind of operation will become routine. Only with a space station can we do things like this routinely.

Second, the space station will be a space laboratory. I do not need to go into details, but there clearly is something to exploit here.

Third, the space station will be a stepping-stone to other places. I have already mentioned that there is remarkable agreement as to what we should do next. I heard Edward Teller talk about establishing a base on the moon before the end of this century, and I heard Congressman Brown say the same thing. I admit that those two gentlemen do not always agree on things, but on this they are in remarkable agreement. That is important. The space station is necessary if we are to establish a base on the Moon. If you look at the energy requirement, rather than the distance, once you are in Earth orbit, you are 75 percent of the way to wherever you want to go in the solar system. That, of course, is why we want to have the space station. Fourth, and most important, the space station is a symbol of our technical competence, and that is an important point, as the President recognizes.

All our national security space programs are also in excellent shape. We have strong capability for observation and communication—for all the things that are important to maintain our current, relatively stable situation. The existence of these systems is critical because they reduce the terrible uncertainty that always faces us when making decisions in times of crisis. When we talk about the future and move on to the SDI, there seems to be general agreement that useful things in that direction can be done.

There is a debate as to whether SDI should be done, but no debate as to whether it can be done. I did not notice any hands go up yesterday at the question: "How many people in this room think SDI simply can't be done?" So, to summarize the good news, we are in rather strong agreement on the bulk of the technical programs on the civil side and on the projection of our technical capability.

Now let me turn to the problems. One concerns the nature of the arms control process today and what we can achieve by pursuing negotiations with the Soviets in the area of arms control. The other problem was stated eloquently by Congressman Brown yesterday: If we are serious about something like strategic defense, where do we get the money? Now I cannot summarize an issue about which there is disagreement, so let me ask a few questions instead.

The people who favor arms control look upon the 1972 ABM Treaty as the centerpiece of our effort with the Soviets to achieve what is called arms control. It was the ABM Treaty that in fact permitted the limitation of offensive weapons. I would like to ask the people who favor arms control to examine whether the ABM Treaty, in the long run, is a good thing. And I want to put that question in the context of technology by saying that the ABM Treaty was written at a time when certain things were technologically feasible and the people who wrote the treaty had some ideas of what was feasible and what was not.

I have to confess that I consciously opted out of the ABM debate in 1967. At the time, I felt that we were talking about something that simply could not be done, and therefore it did not matter whether there was a treaty or not. Now I think the technical situation has changed. This room is full of people who believe that something can be done. Under these circumstances, is the treaty still a good thing? The treaty has in it one important feature I believe we should use. If I were in a position of authority, I would strongly recommend that the United States follow the treaty's recommendation that every 5 years we should sit down with the Soviets.

Let me now address another question to the people who favor going ahead with the SDI full course: Where do we get the money? We are talking about something here that will probably represent the largest investment we have ever made in our national defense. I do not believe that we will either tax ourselves excessively or cut back on social services. We will have to look within the defense establishment for the money and make some appropriate tradeoffs.

I will break the defense budget down not by programs but by commitments. Our NATO commitment is between $30 and $40 billion a year. Would we be willing to cut our troop strength in half in Europe and perhaps get $10 or $12 billion a year in that way to put into SDI? It is a serious question, and the SDI proponents must answer it. Where is the money coming from? What are you willing to trade off against a commitment to the construction of this strategic defense system?

All of my comments about arms control and about the strategic defense problem rest, in the end, on our view of the Soviets. But the view that we have of the Soviets is strongly conditioned by their behavior in the past 40 years. We have come to expect certain things of them, and so we draw conclusions based upon those expectations. I would urge us to keep an open mind. I think the Soviets may not necessarily believe the same way forever. The most interesting conclusion that I draw from a study of recent history is that, by and large, the policy of containment that President Truman and his advisers built in the years just following World War II has been remarkably successful. There have been problems here and there, but the Soviets have not in fact imposed their ideology on Western Europe, as we feared they would do; they have not been able to hold on to the Far East; and the Chinese are no longer their allies. We need to keep those successes in mind as we seek a new policy.

It helps to look back upon successful dealings with the Soviets. Eugene Rostow was right when he said that the Soviets are not like us. They are also not constant; they are changing. We are told that we should not seek victory in our struggle with the Soviets. If victory means their destruction, I agree, but if victory means that they will do what the Chinese have done, then I do not agree. We need to formulate this later objective clearly and then build an arms control and SDI strategy around it. Is all this beyond the realm of imagination? I do not think so. Our relationship with the Soviets is dynamic. They have terrible problems, and those problems are going to get worse in the coming years. And whereas I do not think they will respond to *anything* we do, we can get them to act in response to their own internal problems if we understand those problems and act accordingly.

In determining what we can and should do, let me come back to the points on which we agree. The single strength we have in dealing with them is our technical strength. That is what they really fear, so it is vital for us to understand this fact and then to use it in our negotiations and our dealings with them.

ACRONYMS

ABM Anti-ballistic Missile
AFSATCOM Air Force Satellite Communications
ALMHV-Air-launched Miniature Homing Vehicle
ALT Approach and Landing Test
ALTAR Air-Launched Miniature Homing Vehicle.
ANIK Canadian Communications Satellite
ARPA Long-Range Tracking and Instrument Radar

BMD Ballistic Missile Defense

C^3I Command, Control, Communications and Intelligence
CELV Complement Expendable Launch Vehicles
CSOC Consolidated Space Operations Center
COMSTAR Communications Satellite (major contractor, Hughes Aircraft)

DAMA Demand Assigned Multiple Access
DEFCON Defense Condition
DDN Defense Digital Network
DMSP Defense Meteorological Support Program
DSAT Defense of Satellite
DSCS Defense Satellite Communications System
DSN Defense-Switched Network

ELINT Electronic Intelligence
ELV Expendable Launch Vehicle
EORSAT Electronic Warfare Data Relay Satellite (Electro Optical Rectifier)

FEP Fluorinated Ethylene Propylene
Front End Processor
Fluoral Ethel Propane
FLSATCOM Fleet Satellite Communications System

GAPSAT Geological Applications Program Satellite
GLONASS Soviet Satellite Navigation System

GPS Global Positioning System
GPSCS General Purpose Satellite Communications System

HOE Homing Overlay Experiment

ICBM Intercontinental Ballistic Missile
INCA Intelligence Communications Architecture
INS Inertial Navigation System
IRBM Intermediate-Range Ballistic Missile

LEASAT Leased Satellite
LORAN Long-Range Navigation

MARISAT Maritime Satellite
MILSATCOM Military Satellite Communications
MILSTAR Extremely High Frequency Communications Satellite System
MIRV Multiple Independently-Targetable Reentry Vehicles

NASA National Aeronautics and Space Administration
NAVSTAR Navigation and Traffic Control System Satellite
NDS Nuclear Detection System
NOAA National Oceanographic and Atmospheric Administration

OMEGA Classified Air Force Program Navy VLF Navigation System for Military and Commercial Aircraft
OTA Office of Technology Assessment

P^3I Pre-Planned Product Improvements
PPS Precise Positioning Service

RORSAT Radar Ocean Reconnaissance Satellite

SATCOM Satellite Communications, part of DSCS (Defense Satellite Communications System)
SATKA Surveillance Acquisition, Tracking, and Kill Assessment
SCORE Signal Communications by Orbiting Relay Equipment
SDS Shuttle Dynamic Simulation (Simulator)
Software Design Specifications
Steering Damping System
SHF Super High Frequency
SLBM Submarine-Launched Ballistic Missile
SPS Standard Positioning Signal
SRAM Short-Range Attack Missile, also known as Alpha Gulf Mary -69 a supersonic air-to-ground nuclear missile

SRB Solid Rocket Booster
SSS Sound Suppression System
Space Shuttle System
Stage Separation Subsystem
Station Set Specification
Subsystem Segment
SPS Standard Positioning Signal
STS Space Transportation System

TACAN Tactical Air Command and Navigation System
Tactical Air Navigation

VOR/DME Very High Frequency Omni-directional Range Distance-Measuring Equipment

WESTAR Western Union Satellite
WWDSA Worldwide Digital System Architecture

BIOGRAPHIES

KEYNOTE SPEAKER

Vice President George Bush

The Vice President was born in Milton, Massachusetts, in 1924. After service as a navy pilot he graduated Phi Beta Kappa from Yale University. His business experience centered in the Dresser and Zapata companies before he was elected to the House of Representatives in 1966 from the Texas 7th District. Mr. Bush was US Ambassador to the United Nations from 1971 to 1973 and Chairman of the Republican National Committee before serving for more than a year as Chairman of the US Liaison Office in the People's Republic of China. He was subsequently Director of Central Intelligence. Mr. Bush was sworn in as 43rd Vice President of the United States on January 20, 1981.

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The chief of the joint planning staff for space, Office of the Joint Chiefs of Staff, was born in Harrisburg, Pennsylvania, in 1933. He is a graduate of the US Naval Academy, the Air Force Institute of Technology, and the Industrial College of the Armed Forces. He has worked with the Atlas and Minuteman programs, taught at the US Air Force Academy and saw service in Vietnam before being assigned to Headquarters Aerospace Defense Command. More recently, he has been Director of Space and Missile Warning Operations and Deputy Chief of Staff, Intelligence, for the US Air Force Space Command and the North American Aerospace Defense Command.

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Henry F. Cooper, born November 8, 1936 in North Augusta, South Carolina, is Assistant Director for Strategic Programs of the Arms Control and Disarmament Agency. He earned a B.S. and M.S. from Clemson University and a Ph.D. from New York University. As a nationally recognized expert on nuclear weapons, he has served on many national and government committees, panels, and working groups and has authored numerous publications on scientific and technical issues.

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Colin S. Gray, born in Oxfordshire in 1943, is President of the National Institute for Public Policy. Dr. Gray studied at the universities of Oxford and Manchester. He has concentrated on strategic studies and international politics. He is author of a number of books and articles dealing with strategic and other arms-related matters.

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Dr. Hans Mark, born in Mannheim, Germany, on June 17, 1929, is former Deputy Administrator of the National Aeronautics and Space Administration. He earned a B.S. from the University of California, then earned a Doctorate in physics at MIT and an Honorary Doctorate of Science at the Florida Institute of Technology. His many assignments have involved him in physics and engineering, and he has written and taught extensively on these subjects.

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Dr. Edward Teller, born in Budapest, Hungary, on January 15, 1908, is Associate Director Emeritus. Lawrence Livermore National Laboratory. Educated extensively in the United States and abroad, his advanced degrees include Doctorates of Science from Yale and Mt. Mary College, and Ph.D.s from the University of Leipzig and from Tel Aviv University. His career has centered on nuclear energy and in nuclear weapons development. He has often written and taught on these topics.

America Plans for Space

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